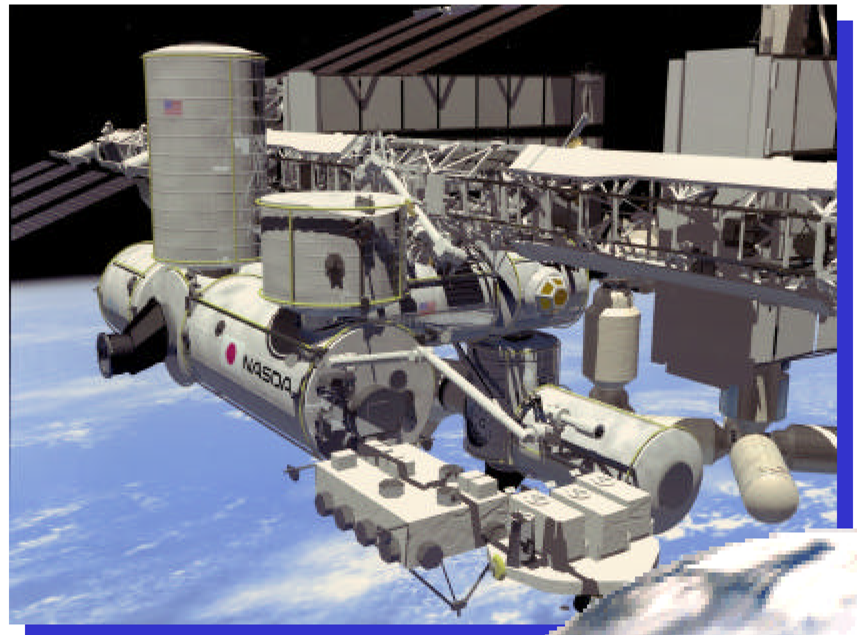
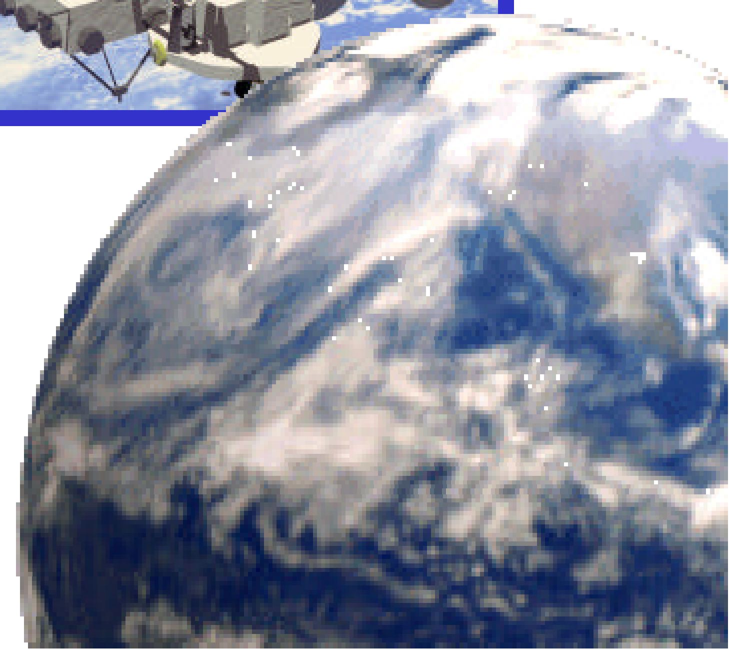
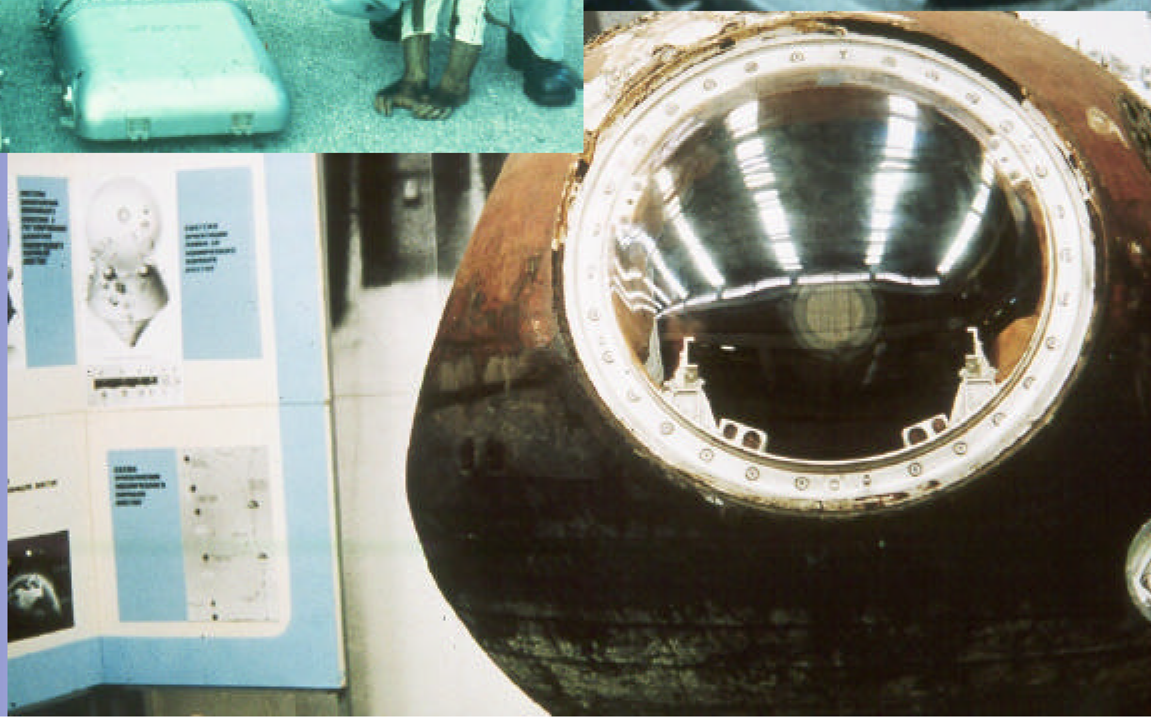
Space Medicine – A Historical Overview of the Medical Issues Associated with Human Space flight

Definition

Space medicine is an evolving multidisciplinary specialty dealing with the medical problems associated with human space travel







Space Medicine 3

Phases of Human Space Exploration

1. Could humans survive in space?
   - NASA Mercury and Gemini missions
   - Soviet Vostok 1 - 4 missions
2. Could humans function in space?
   - NASA Mercury and Gemini missions
   - Soviet Vostok 3 - 6 missions
3. What physiologic Changes Occur in Space?
   - NASA Gemini missions
   - Soviet Voskhod missions

Phases of Human Space Exploration

4. Could humans survive EVA in space? Could humans control spacecraft rendezvous and docking on orbit?
   - Soviet Voskhod 2 (1965)
   - NASA Gemini (1965)
5. Could humans successfully travel to the moon and safely return?
   - NASA Apollo 11 mission
6. Could humans function in space for prolonged periods of time?
   - NASA Skylab and STS program
   - Soviet Soyuz and Salyut program

Phases of Human Space Exploration

7. Could space be made readily accessible for the purposes of science and space exploration?

   • STS Program

8. Could humans use space station platforms to conduct science during long duration missions?

   • MIR Phase 1 Program

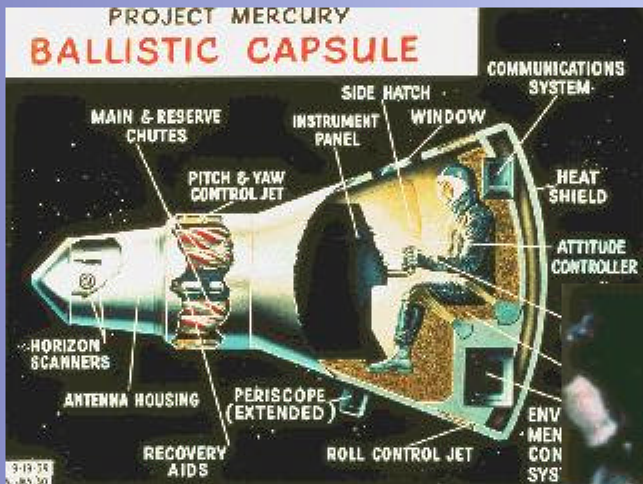
9. Can humans from wide ranging cultures and backgrounds successfully build and utilize an orbital platform to expand knowledge and further space exploration?

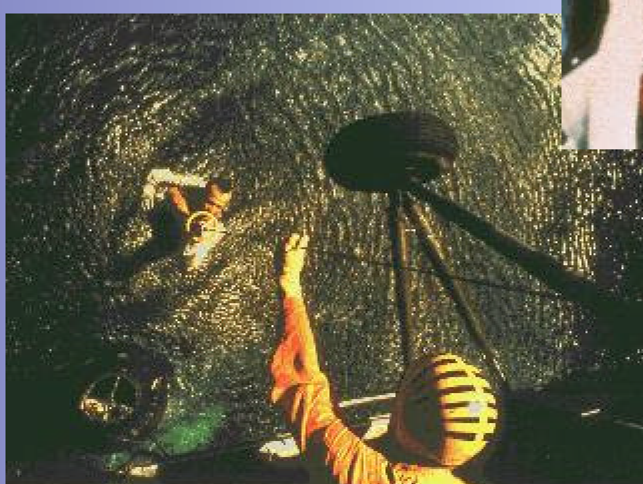
   • ISS Program

10. The next phase – human exploration beyond low earth orbit.

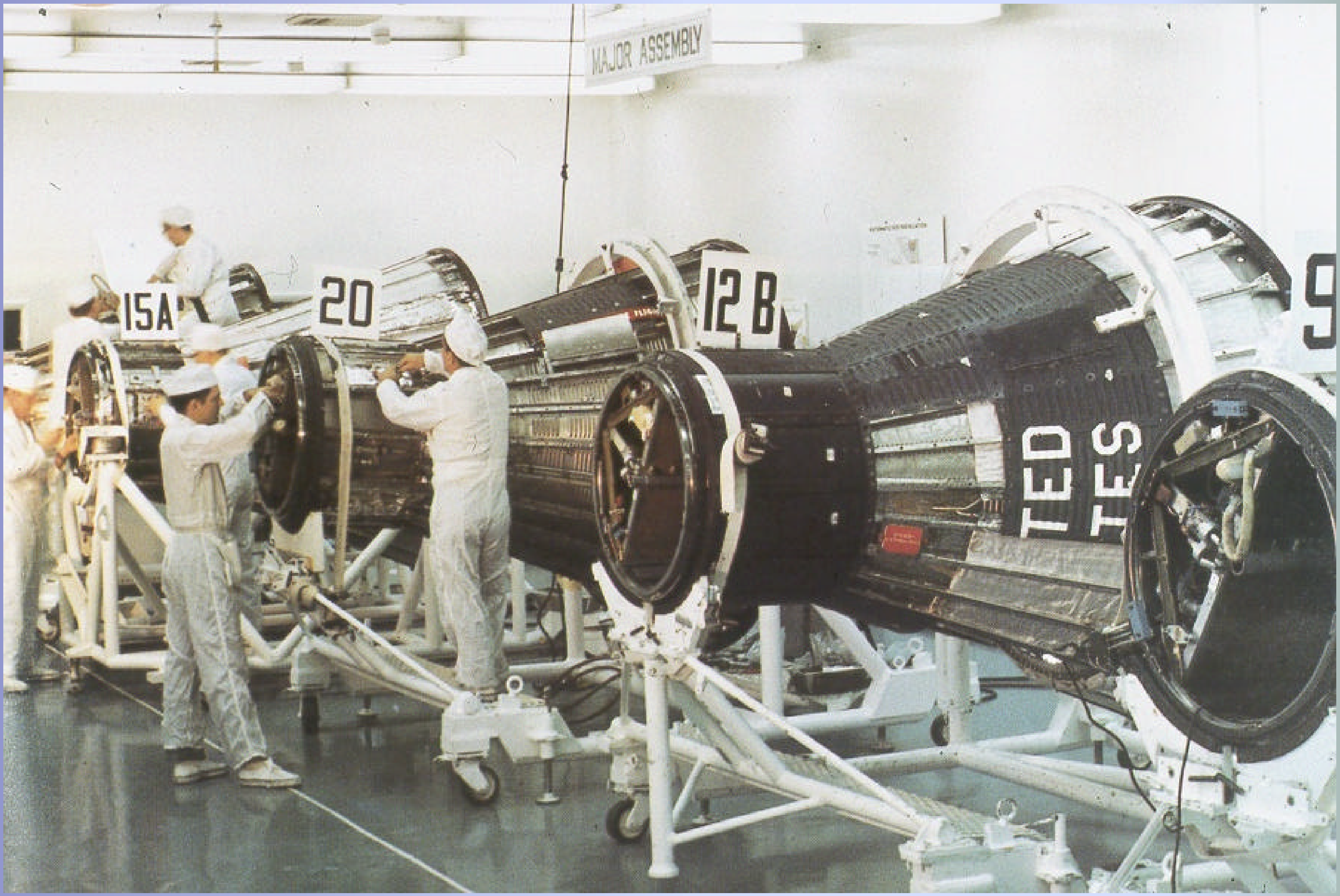
Mercury Program

Mercury Program





Mercury Program



Mercury Program

Mercury Program

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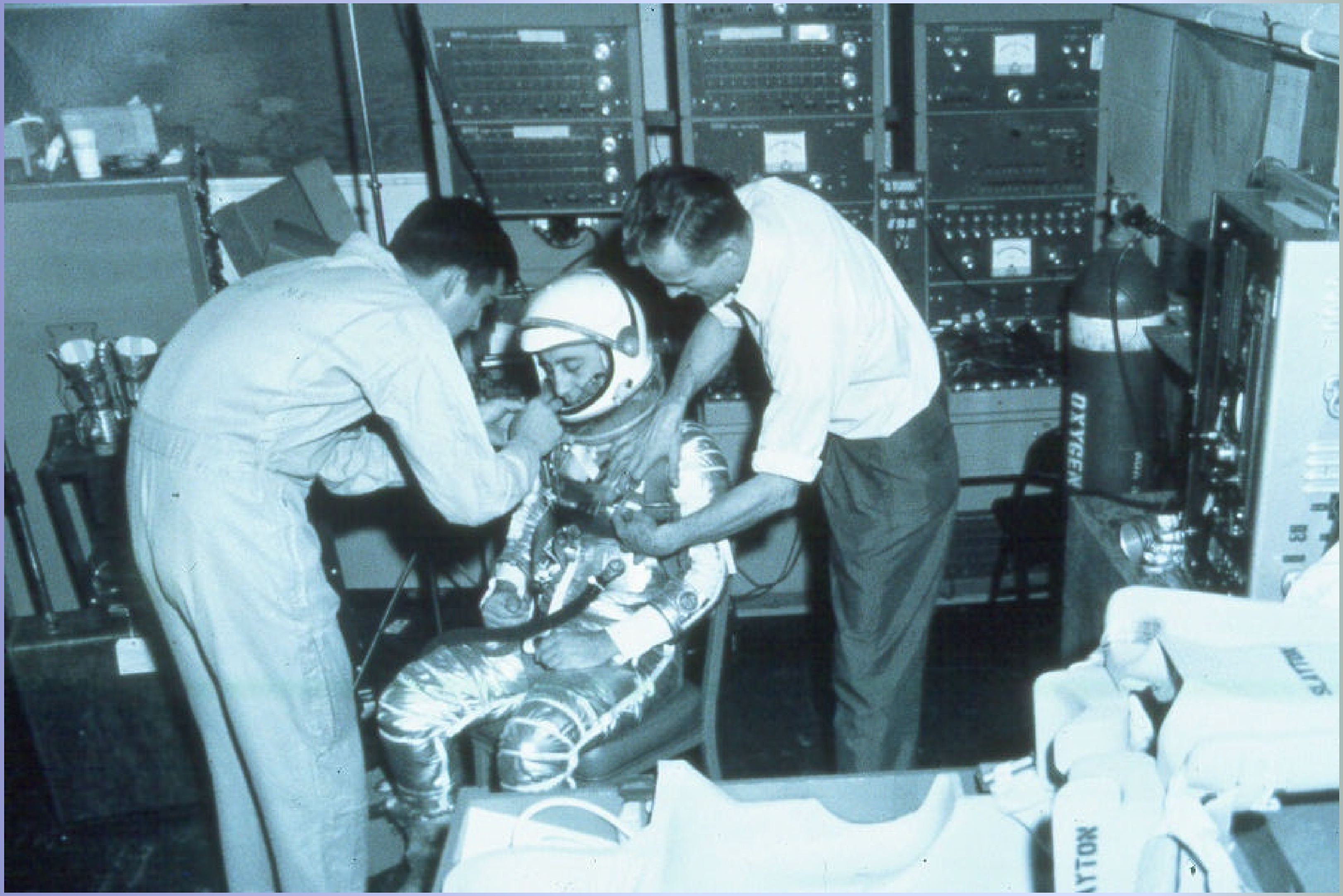
Mercury Program



Spacecraft Life Support Systems
Mercury Program

Cabin system

- Provided a 28 hour flight capability based on an oxygen consumption of 500 cc/minute at standard temperature and pressure
- Cabin pressurization of 5.1 PSIA: pressure level was chosen as the best compromise to provide necessary oxygen partial pressure, efficient use of supply for emergency modes of operation, a pressure offering small differential change during sudden decompression emergencies and a level for which decompression sickness would be minimal.
- Pressure controlled between 4.0 and 5.5 PSIA
- Heat exchanger system was designed for an astronaut metabolic heat production of 500 BTU per hour.
- Potable water system consisted of a flexible water pouch containing 6 lbs. of water with a flexible hose and drinking tube.

Spacecraft Life Support Systems Mercury Program

Pressure Suit Control System

- Would operate at a pressure of 4.6 PSIA following cabin decompression.
- Oxygen was forced into the suit at a torso connection by a battery-powered electric blower body.
- Evaporative cooling took place and a mixture of carbon dioxide water vapor and oxygen was produced - this gas mixture left the suit by helmet connection.
- Odors removed by activated charcoal, carbon dioxide was removed by LiOH.
- Initially an oxygen/nitrogen mixture was suggested to mitigate the risk of fire. Early ground tests showed that nitrogen could concentrate in the pressure suit circuit since the flow of oxygen into the suit was initiated by a slight negative pressure on a demand regulator.
- Cabin atmosphere was changed 100% oxygen and special emphasis was placed on material selection and quality control to reduce fire risk.

Medical Events – Mercury Program

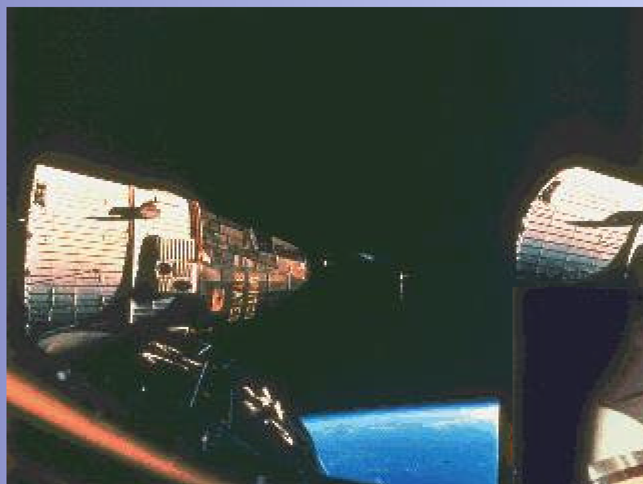
- Vital signs: no change
- Serum and plasma enzymes: elevated peptidase leucylamino 3 hrs post-flight persisted 45 hrs post flight (MR-3)
- Decreased G-tolerance: none
- Skin breakdown: erythema at biosensor sites, superficial abrasions second and third fingers of right hand (MA-6)
- Motion sickness: none
- Tachycardia: launch, re-entry
- Cardiac arrhythmias: none
- High blood pressure: none
- Low blood pressure: none
- Orthostatic intolerance: post flight
- Fatigue: 2 crew members noted to appear fatigued post flight

Medical Conclusions – Mercury Program

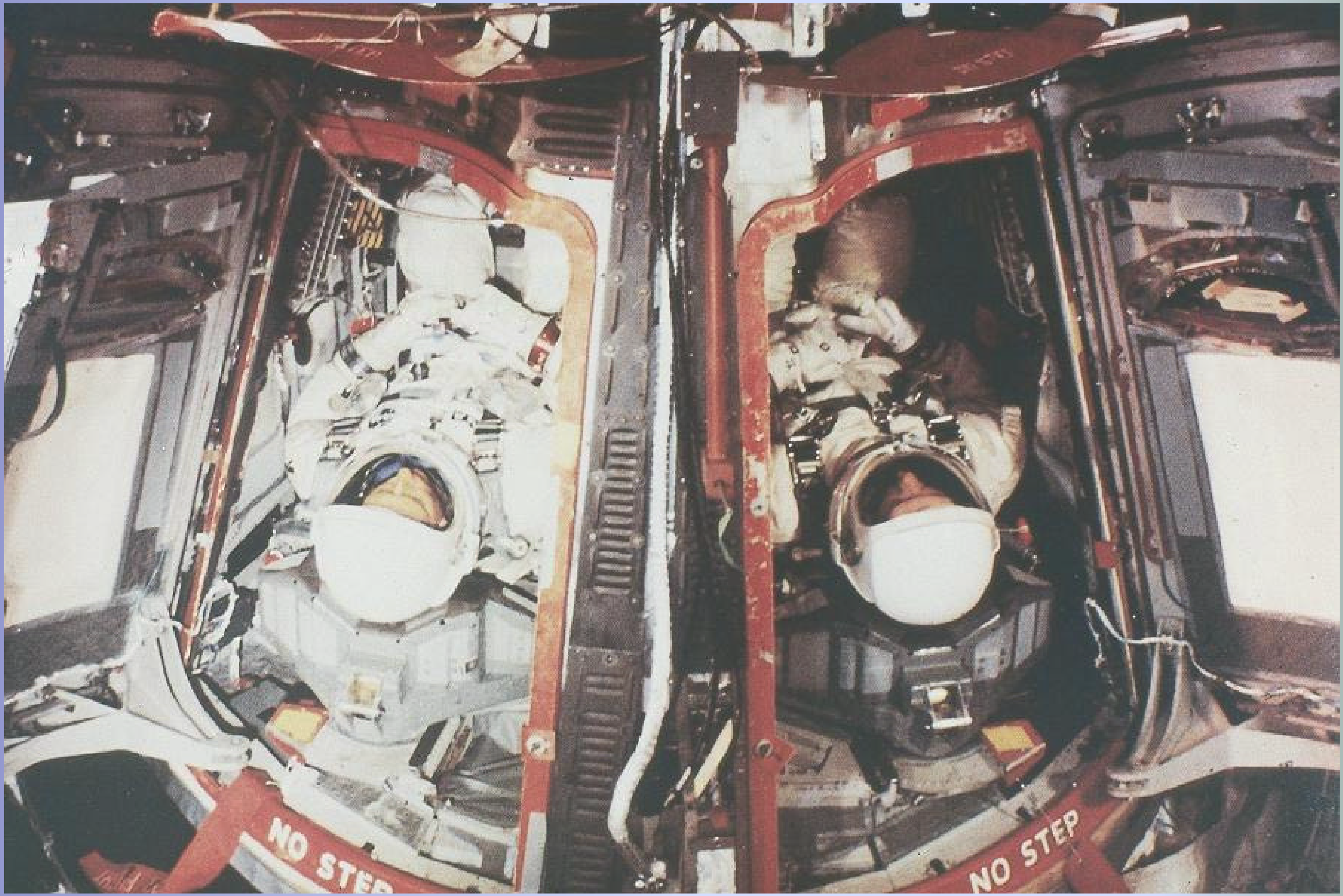
Principal Conclusions:

- There was no evidence of loss in pilot performance capability.
- All measured physiological functions remained within normal limits.
- There was no evidence of abnormal sensory or psychological response.
- The radiation dose received was considered medically insignificant.
- An orthostatic rise in heart rate and fall in blood pressure was noted post flight and it persisted for 7 to 19 hours after landing.

Gemini Program



Gemini Program



Spacecraft Life Support Systems
Gemini Program

Cabin System:

- ECS maintains a 100% oxygen atmosphere, controls the temperature of the crew and spacecraft equipment, and provides drinking water supply & means of disposing of wastewater.
- Subdivided into a suit subsystem, a water management subsystem, and a coolant subsystem.
- Suit subsystem divided into 3 systems: suit, cabin and oxygen supply systems.
- Nominal 5.1 PSIA 100% oxygen environment.
- Study undertaken to determine possible oxygen toxicity with exposure of humans for 14 days to the 100% oxygen at 5 PSIA atmosphere selected for the Gemini spacecraft. It was determined that this would not impose any physiological problems.
- From these findings, the Apollo program office elected to use this atmosphere in the Apollo spacecraft.

Spacecraft Life Support Systems
Gemini Program

Cabin System - Water Management

- Water management subsystem: included a 16 pound capacity water tank, a water dispenser, and the necessary valves and controls all located in the cabin plus a water storage system located in the adapter.
- Wastewater disposal accomplished by 2 methods. Condensate from the suit heat exchangers routed to the launch cooling heat exchanger for boiling if additional cooling is required or is dumped overboard.
- Urine is dumped directly overboard.

Spacecraft Life Support Systems
Gemini Program

Cabin System

Coolant Subsystem

- Provides cooling for the crew and thermal control for spacecraft components.
- Cabin fan circulates gas through the heat exchanger to provide cooling for cabin equipment.
- System consists of two completely redundant circuits each having redundant pumps using heat exchangers and cold plates for cooling.
- Pre-launch cooling is provided through the ground cooling heat exchanger.

Spacecraft Life Support Systems
Gemini Program

Pressure Suit Control System

- Compressors circulate oxygen through the system at approximately 11 cubic feet per minute through each space suit.
- Carbon dioxide and odors are removed from the oxygen by an absorber containing lithium hydroxide and activated charcoal.
- Oxygen can be cooled in the suit heat exchanger to 48^{o} F - actual temperature is a function of crew activity. Coolant subsystem operating mode and system adjustments made by the crew.
- Water given off by the crew as perspiration and expiration is condensed in the suit heat exchanger and routed to the launch cooling heat exchanger.
- Demand regulators maintain a minimum suit pressure of 3.5 PSIA anytime the cabin pressure drops below that level.

Flight-Crew Equipment
Gemini Program

Food system

- Consists of freeze-dried rehydratable foods and beverages vacuum packed in a laminated plastic bag.
- The average menu provides between 2000 and 2500 calories per day.
- Drinking water dispenser designed to mate with the drinking port of the space suit helmet. A digital counter on handle recorded each increment dispensed.

Urine collection system

- Consisted of a portable receiver with a latex condom catheter.

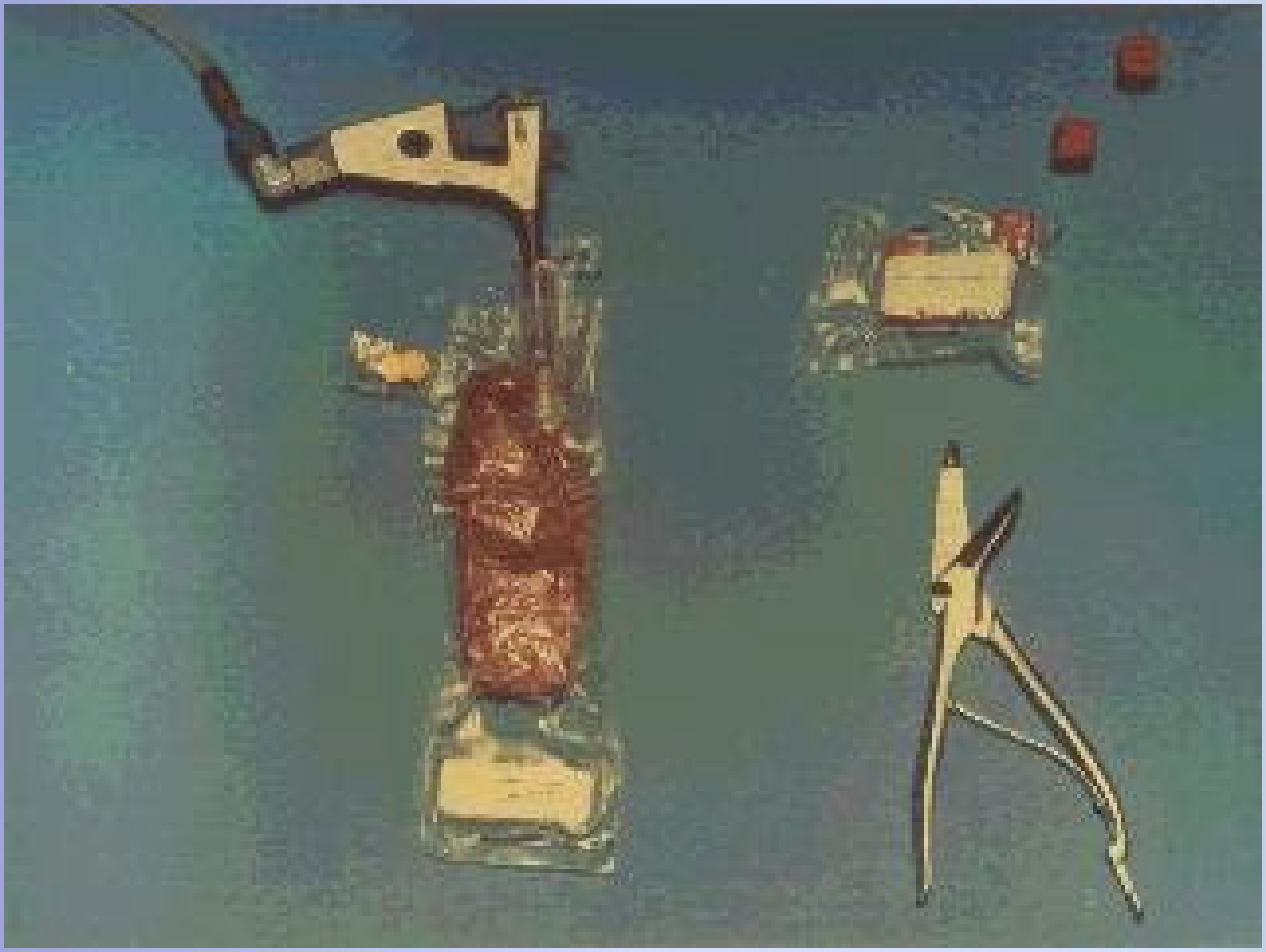
Defecation system

- Consisted of individual plastic bags with adhesive lined circular tops and a disinfectant packet to eliminate bacterial growth. In-flight use required considerable care and effort.

Personal hygiene system

- Included hygiene tissues in fabric dispenser packs, fabric towels, wet cleaning pads, toothbrushes and chewing gum for oral hygiene.

Gemini Food System



Gemini Program

EVA – Gemini Program

G4C suit: EVA accomplished on 5/10 Gemini missions (12 hrs 25 min)

- Primary oxygen flow to the suit was supplied through a 25 ft. umbilical hose which also contained communications and bioinstrumentation wiring.
- Normal open loop oxygen flow was provided at 8.2 pounds per hour.
- A small chest pack called the ventilation control module was developed for control of the space suit pressurization and ventilation.
- Suit pressure was maintained at 4.2 PSIA.
- The hand-held maneuvering unit consisted to of a system of manually operated cold gas thrusters.
- During the initial egress activities and during ingress, the oxygen flow at 8.2 pph did not keep the EVA pilot cool and overheating/visor fogging occurred at these times.

Gemini Program – Medical Events

Dysbarism: none (Gemini 10)
Circadian disruption: none
Decreased G-tolerance: none
Skin breakdown: dryness/dandruff
Sleeplessness: minor interference
Vision: no reduction in visual acuity
eye irritation
ENT: nasal stuffiness/hoarseness
Motion sickness: none
Pulmonary atelectasis: none
Tachycardia: launch, re-entry, EVA
Cardiac arrhythmias: none
High blood pressure: none
Low blood pressure: none
Orthostatic intolerance: none

Reduced cardiovascular response to exercise: none
Hematology: absolute neutrophilia
decreased red cell mass
Reduced blood volume: moderate
Reduced plasma volume: minimal
Weight loss: variable
Bone demineralization: minimal
Loss of appetite: varying caloric intake
Renal stones: none
Urinary retention: none
Muscular atrophy: none, reduced exercise capacity
Hallucinations: none
Fatigue: minimal
Stimulants: occasionally before entry

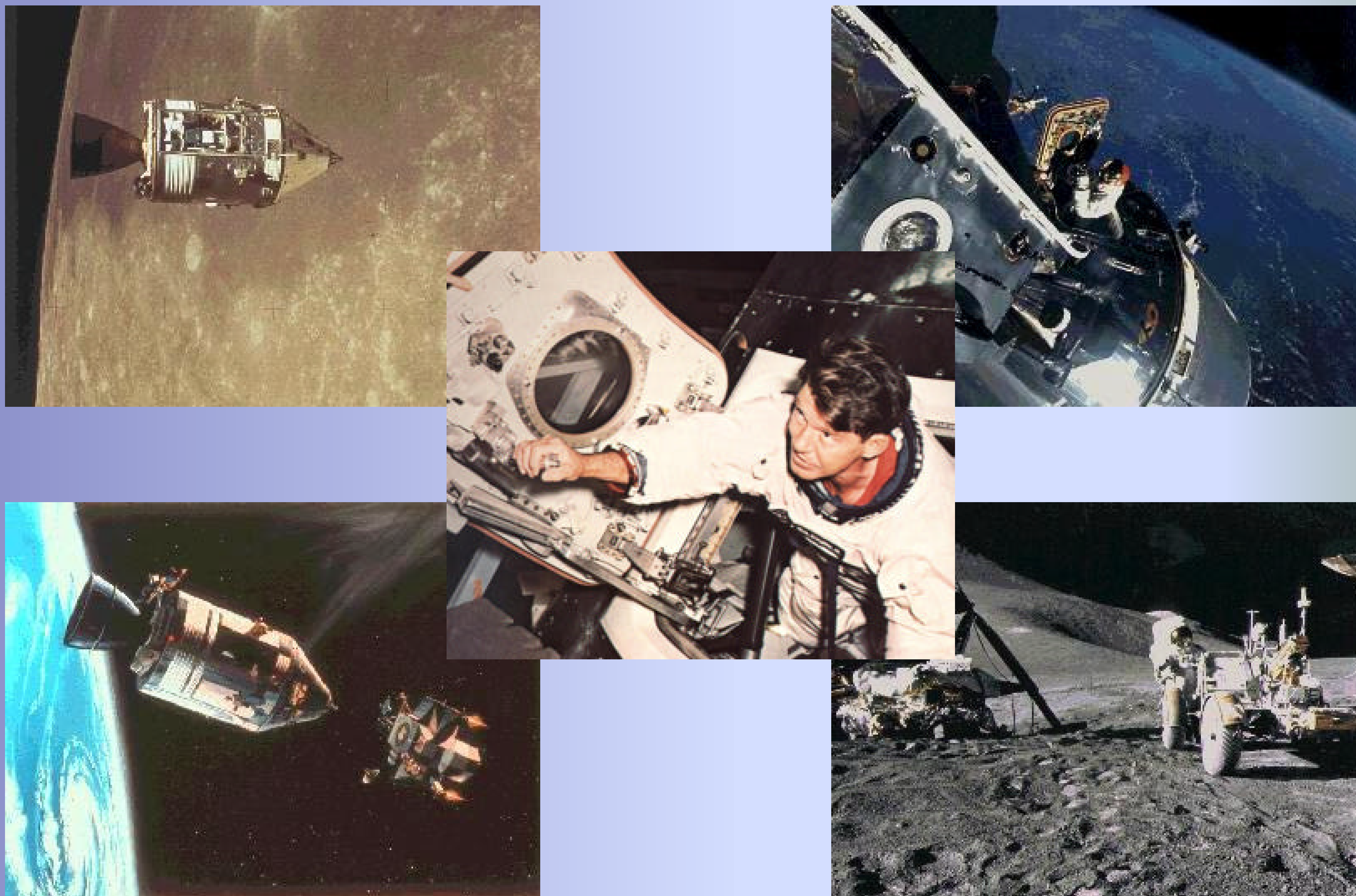
Gemini Program-Medical Issues

- Quarantine pre-flight was rejected as impractical. A number of short-lived flu like syndromes, 1 exposure to mumps and 1 incident of streptoccal pharyngitis developed in the immediate pre-flight period.
- Medications were provided for sedation prior to launch and stimulation prior to re-entry. A drug kit was made available for in-flight prescription.
- **Aspirin** has been used in-flight for occasional mild headache and for relief of muscular discomfort. **Amphetamines** were taken on several occasions by fatigued crew prior to re-entry. A **decongestant** was used to relieve nasal congestion and alleviate the necessity for frequent clearing of the ears prior to re-entry. The **motion sickness medication** was taken in 1 instance prior to re-entry to reduce motion sickness resulting from motion of the spacecraft in the water. An **inhibitor of gastrointestinal propulsion** was prescribed when necessary to assist in avoiding in-flight defecation. No injectors were used in-flight.

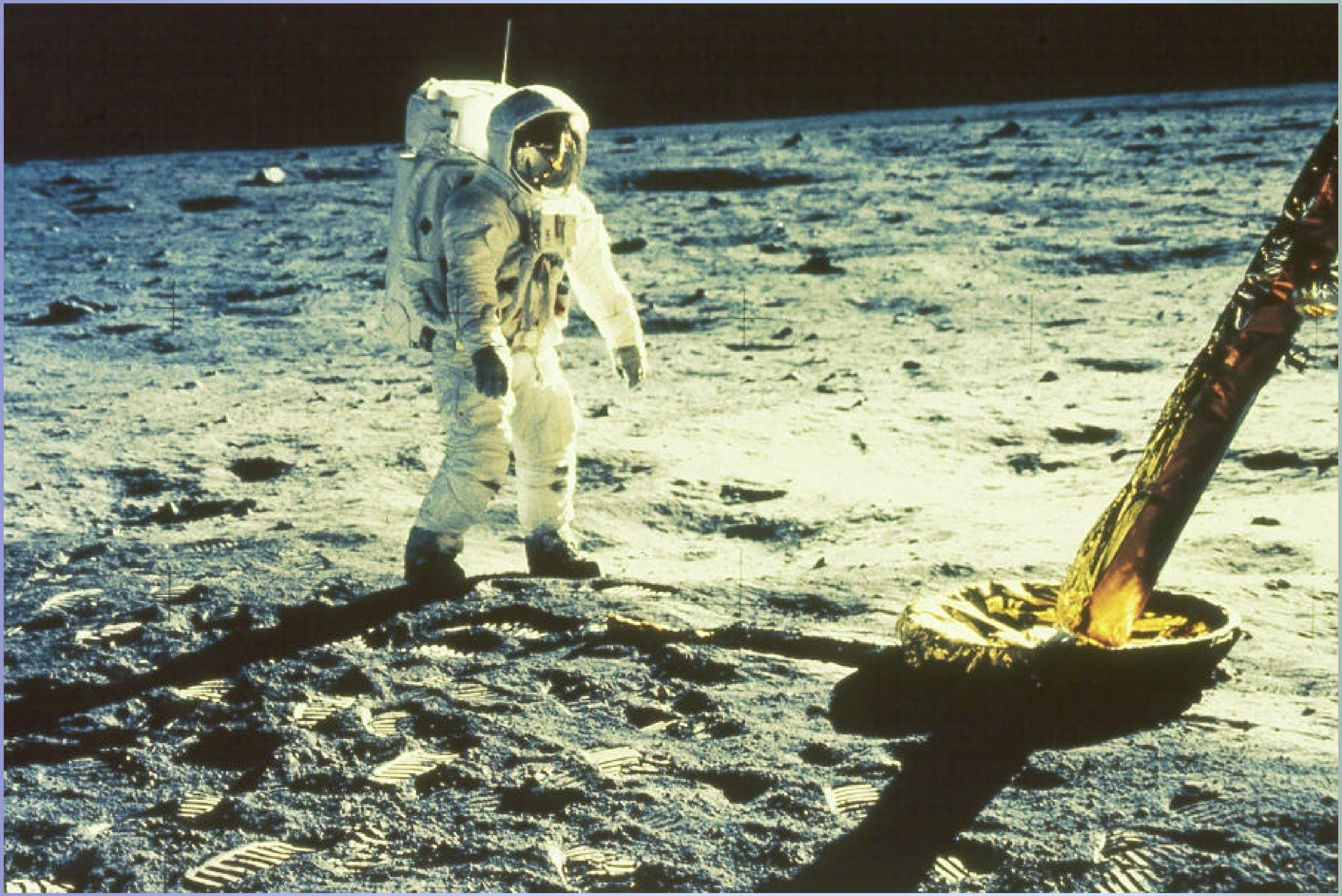
Biomedical Conclusions - Gemini Program

- Extended Project Mercury finding that humans can tolerate exposure to the space environment quite well. No significant performance detriment was noted.
- Post flight orthostatic hypotension persisting for some 50 hours was observed during tilt table tests.
- A decrease in red cell mass of the order of 5-20 % was noted.
- Bony demineralization was observed as a percent change in the density of the os calcis.
- No adverse psychological reactions were observed even during 14 days confinement in a restrictive cabin environment.
- No vestibular disturbances were reported.

Apollo Program



Apollo Program



Spacecraft Life Support Systems
Apollo Program

- Atmospheric tests up to 30 days duration indicated the 100 % oxygen 5 PSIA atmosphere was physiologically adequate. Studies indicated that this atmosphere was associated with aural atelectasis, eye irritation and nasal congestion.
- Medical investigations associated with Gemini manned space flight suggested hematologic changes resulting from exposure to a single gas atmosphere. Although the causes and implications of the decrease in red cell mass were not completely understood, they were not considered to be a deterrent to the use of a 100 % percent oxygen at 5 PSIA for Apollo spacecraft.
- After the Apollo 1 fire, procedures were modified to use a 60 % oxygen and 40 % nitrogen mixture to reduce the fire hazard.

Spacecraft Life Support Systems
Apollo Program

Command Module ECS:

- ECS was broken down into the oxygen subsystem, pressure suit circuit subsystem, water subsystem, coolant subsystem, and waste management subsystem.
- Oxygen atmosphere in a pressurized cabin of 5 PSIA, normal shirt sleeve environment except for critical mission phases.
- Cabin pressure maintained at 3.5 PSIA under certain defined emergency conditions.
- After Apollo 1 the CM was launched with 60 % oxygen and 40 % nitrogen gas composition which eventually was built up to almost 100 % oxygen through leakage makeup with oxygen.
- The atmospheric pressure and composition after launch remained between 4.71-5.1 PSIA at almost 100 % oxygen for the duration of each mission including the time in the lunar module.

Spacecraft Life Support Systems
Apollo Program

Carbon dioxide concentration:

- Carbon dioxide levels regulated optimally at 3.8 torr; maximum limit a 7.6 torr; the emergency limit was 15.0 torr. Carbon dioxide levels recorded by sensors in the CM and LM remained well below the limit except for the return flight of the Apollo 13 spacecraft when they rose to a maximum of 14.9 torr in the LM.
- Carbon dioxide removal by LiOH limited to a partial pressure of 7.6 mm Hg.

Thermal comfort:

- Design range for temperature and humidity control in the Apollo CM was 70-80^{o} F with a relative humidity of 40-70 %. During the Apollo 13 mission the LM ECS provided a habitable environment for approximately 83 hours after which cabin temperatures ranged between 49-55^{o} F.

Spacecraft Life Support Systems
Apollo Program

Water subsystem:

- CM potable water was produced as a byproduct of fuel cell operation stored the water and chilled or heated the water for drinking and food reconstitution.
- Waste water was collected, stored and provided to the evaporator for evaporator of cooling. Water in excess of system requirements was dumped overboard through a heated water dump nozzle.
- LM water supplies were loaded in storage tanks before liftoff. No heating or cooling was provided for LM water.

Spacecraft Life Support Systems
Apollo Program

Dust control:

- Effective control of lunar dust was a problem encountered with the start of the lunar landing missions.
- Transfer of crew and materials back to the command module resulted in a contamination of the CM atmosphere.
- To speed up the capture of suspended material a filter was developed for use with the cabin fans.
- To assist in removing dust from suits and sample containers a hand-held vacuum cleaner was developed that used the qualified suit circuit compressor has a blower. Heavy usage however tended to clog the inlet screen and impeller and required frequent cleaning.

Medical Objectives - Apollo Program

1. Ensuring crew safety from a medical standpoint. This objective required that every effort be made to identify, eliminate, or minimize anything which posed a potential health hazard to the crew.
2. Improving the probability of mission success by ensuring that sufficient medical information was available for management decisions.
3. Preventing terrestrial contamination from the lunar surface.
4. Continuing to further of the understanding of the biomedical changes incident to space flight. This objective was formulated to detect, document, and understand changes occurring during space flight.

Pre-flight procedures - Apollo program

Major objectives:

- The discovery of latent illnesses during the process of astronaut selection and preparation for missions.
- The implementation of the health stabilization program and other preventive measures.
- Determination of individual drug sensitivity to the contents of the Apollo medical kits.
- Providing baseline data against which to compare post flight data for determination of space flight effects.
- Prevention of any situation which might delay or otherwise interfere with operational aspects of the mission.

Health stabilization - Apollo program

Mission	Illness	# of crew involved	Mission phase
Apollo 7	U. R. I.	3	Preflight, Inflight
Apollo 8	Viral gastroenteritis	3	Preflight, Inflight
Apollo 9	U. R. I.	3	Preflight
Apollo 10	U. R. I.	2	Preflight
Apollo 11	none		
Apollo 12	Skin infection	2	Inflight
Apollo 13	Rubella infection	1	Preflight
Apollo 14	none		
Apollo 15	none		
Apollo 16	none		
Apollo 17	Skin infection	1	Preflight

In-flight medical problems-Apollo crews

Symptom/finding	Etiology	Number of cases
Barotitis	Barotrauma	1
Cardiac arrhythmia	Undetermined, possibly linked with potassium deficit	2
Eye irritation	Fiberglass Spacecraft atmosphere	1 4
Dehydration (Apollo 13)	Reduced water intake	2
Flatulence	undetermined	3
G. U. infection with prostatic congestion	Pseudomonas aeruginosa	1
Headache	Spacecraft environment	1
Head cold	undetermined	3
Nasal stuffiness	Zero gravity	2
Pharyngitis	undetermined	1
Rhinitis	Oxygen, low relative humidity	2

In-flight medical problems-Apollo crews

Symptom/finding	Etiology	Number of cases
Respiratory irritation	Fiberglass	1
Rash, facial, inguinal	Contact dermatitis Prolonged wearing UCD	1 1
Skin irritation	Bio-sensor sites Fiberglass Undetermined	11 2 1
Seborrhea	Activated on orbit	2
Shoulder strain	Lunar core drilling	1
Subungual hemorrhages	Glove fit	5
Stomach awareness, N/V	Labyrinthine	8
Stomatitus	Apthous ulcers	1
Excoriation ureatal meatus	Prolonged wearing UCD	1
Urinary tract infection	Undetermined	1
Decompression sickness		1

Apollo Missions – Radiation Dose

Mission	Average Dose (Rad)
Apollo 7	0.16
Apollo 8	0.16
Apollo 9	0.20
Apollo 10	0.47
Apollo 11	0.18

Work/Sleep Cycles – Apollo Program

Primary factors contributing to sleep disruption:

1. Cyclic noise disturbances resulting from thruster firings, communications, or movement within the spacecraft.
2. Staggered sleep periods.
3. Significant displacement of the astronaut’s normal diurnal cycle.
4. The so-called command pilot syndrome.
5. The unfamiliar sleep environment.
6. Excitement.

Flight crew equipment-Apollo program

Food:

- In-flight food consumption was inadequate to maintain metabolic balance (caloric intake was less than calories expended with loss of tissue fluid and electrolytes).
- Meal preparation and consumption required too much time and effort.
- Water for reconstitution of dehydrated foods was off flavor and contained large quantities of un-dissolved hydrogen and oxygen gas.
- Functional failures who occurred in rehydratable food packages.
- Development of a system of foods and packaging that was more familiar in appearance, flavor and method of consumption was required.
- Anorexia occurred during flight (average weight loss six pounds).

EVA Apollo Program

- During EVA, and the suits were pressurized to 3.85 PSIA with 100 % oxygen. No untoward atmospheric effects such as hypoxia, dysbarism, or oxygen toxicity were experienced during any the Apollo missions.

Mission	EVA Experience
Apollo 7, 8, 10	None
Apollo 9	LM Pilot simulated contingency transfer to CM – no problems
Apollo 11	Suit comfortable able to walk, run; LCG worked well
Apollo 12	2 surface EVAs, No problems noted
Apollo 13	No EVA, pressure garments worn as backup
Apollo 14	2 surface EVAs, No problems noted
Apollo 15	CM EVA, 3 Lunar EVAs, Lunar Rover
Apollo 16	CM EVA, 3 Lunar EVAs, Lunar Rover
Apollo 15	CM EVA, 3 Lunar EVAs, Lunar Rover

Apollo Program

Skylab Program

Skylab Program

Objectives:

- **Biomedical and Behavioral Performance:** to determine and evaluate mans physiological responses and aptitudes in space under 0 gravity conditions and his post mission adaptation to the terrestrial environment, through a series of progressively longer missions and to determine the increments by which mission duration can be increased.
- **Man Machine Relationships:** to develop and evaluate efficient techniques using man for sensor operation, discrimination, data selection, and evaluation, manual control, maintenance and repair, assembly, set up and mobility involved in various operations.
- **Long Duration Systems Operations:** to develop techniques for increasing systems life, for long duration habitability, and for long duration mission control; to investigate and develop techniques for in-flight tasks and qualification of advanced subsystems.
- **Experiments:** to conduct solar astronomy and other science, technology, and applications experiments involving man where his contribution will improve the quality or yield of the results.

Skylab Program

- Orbital altitude 270 miles at an inclination of 50 degrees - pressurized to five PSIA 3.7 PSIA oxygen 1.3 PSIA nitrogen
- The NASA life sciences directorate was involved in the development of a number of systems to support nominal mission activity:
  - Biomedical storage containers
  - Food system
  - Medical accessories get and auxiliary drug kit
  - In-flight medical support system
  - Portable carbon dioxide/dew point sensor
  - Operational bioinstrumentation system
- Built from the structure of the Saturn V booster rocket, SIVB stage equipped to house three astronauts for up to three months-volume 294 cubic meters-huge in comparison to Mercury, Gemini, and Apollo spacecraft volume approximately 1-8 cubic meters
- Mission duration Skylab-2 28 days, Skylab-3 59 days, Skylab-4 84 days

Food System – Skylab Program

Food System:

- Galley food system consisted of the food and its packaging, storage and preparation, the galley area, and the food tray. Food included the following types: dehydrated, thermal stabilized, frozen, natural, and intermediate moisture.
- The diet was designed to prevent excessive gastrointestinal gas and result in normal fecal mass and consistency
- Skylab galley consisted of food storage lockers including chillers, freezers, pantries, food preparation area and dining area. The galley contained a limited storage space which was replenished periodically from the bulk food storage areas.
- The heating serving tray was designed to heat and serve food and also to be a work surface when the tray lid is in place. Three of the 4 large cavities contained heaters that are capable of heating food to 149^{o} F

In-flight Medical Support System

- Will provide the capability for mission completion in the event of any illness or injury that could be diagnosed and treated in Earth orbit. It will also provide the capability to stabilize the patient for transport to definitive medical care.
- The IMSS consisted of two basic groups of equipment: diagnostic and therapeutic
- For diagnostic purposes, the IMSS was supplied with the standard clinical tools (stethoscopes, sphygmomanometers, thermometers) in addition to lab equipment for blood analysis, urinalysis and microbiological work.
- For therapeutic purposes the IMSS was supplied with an assortment of drugs both oral and injectable for the treatment and prevention of infection, disease and allergies.
- The IMSS was also outfitted with a minor surgery kit for the care of injuries such as wounds and broken bones

Skylab Medical Kit

Debrief Comments - Skylab Program

- Sleeping compartments were not sufficiently isolated from each other and from the waste management compartment for optimum noise control.
- Mobility and restraint systems were also found to be major factors in the perceived habitability.
- During the first mission none of the astronauts became motion sick although 1 crew member took medication immediately after entry into orbit. No significant performance decrements were noted even during the physically demanding Skylab repair before entering the orbital workshop.
- The second Skylab crew did not take prophylactic medication and experienced severe motion sickness symptoms. One crew member became ill within an hour of achieving orbit while removing his space suit.
- The third Skylab crew took several precautions including flying aerobatic maneuvers the day before the mission and following a schedule of anti-motion sickness medication during the early days of the mission. Despite these measures to crew members experienced motion sickness and one astronaut's symptoms persisted well into the fourth day.

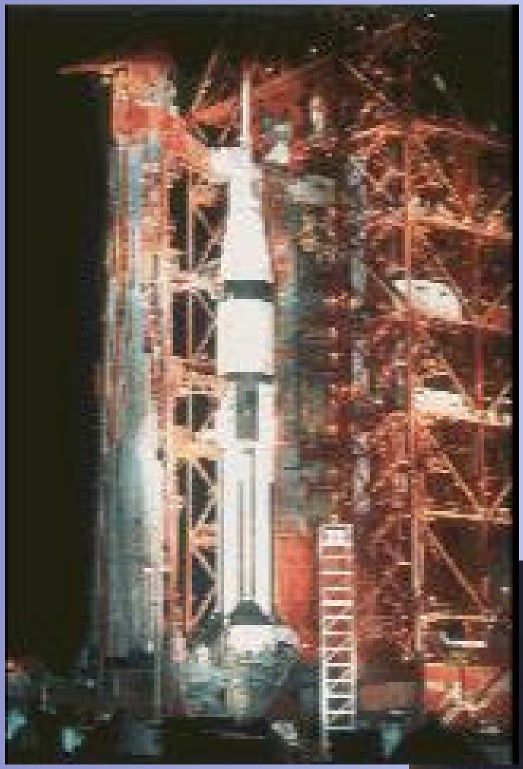
Medical Issues - Skylab Program

- Subjective reports from Skylab crews suggested that space motion sickness could not be predicted with the usual ground based tests but could be alleviated somewhat by prophylactic administration of medications.
- The response of astronauts to provocative orthostatic stress was examined for the first time on orbit. Crew were tested using a lower body negative pressure device before during and after all Skylab missions.
- LBNP imposed orthostatic stress for a period of 25 minutes with application of a maximum negative 50 mm Hg. Customary indices of reduced cardiovascular deficiency were obtained. This was found to stabilize after four-six weeks with no apparent impairment of crew health or performance.
- No mineral losses were observed in the upper extremities but some bone loss was noted in the lower extremities at a rate comparable to those observed in bed rest studies.
- Evidence of muscle loss was obtained from anthropometric studies revealing a marked loss in light volume most of which was restored within 21 days of landing. One-third of the loss was attributed to partial atrophy of the leg muscles while the remainder cost by fluid loss.

Skylab Program Conclusions

- Skylab again demonstrated the value of the human operator in space systems - Commander Charles Conrad and Scientist-Pilot Joe Kerwin spent four hours repairing the lost micrometeoroid Shield and failed solar array wing which had not deployed.
- Guided by ground staff the Skylab team successfully released the solar wing to rectify the problem.
- With sufficient attention to such issues as food service, waste management, and sleep arrangements, a spacecraft can provide satisfactory living and working quarters for long periods.
- Physiological changes were noted to cardiovascular tolerance, muscle strength and bone density which recovered postflight.

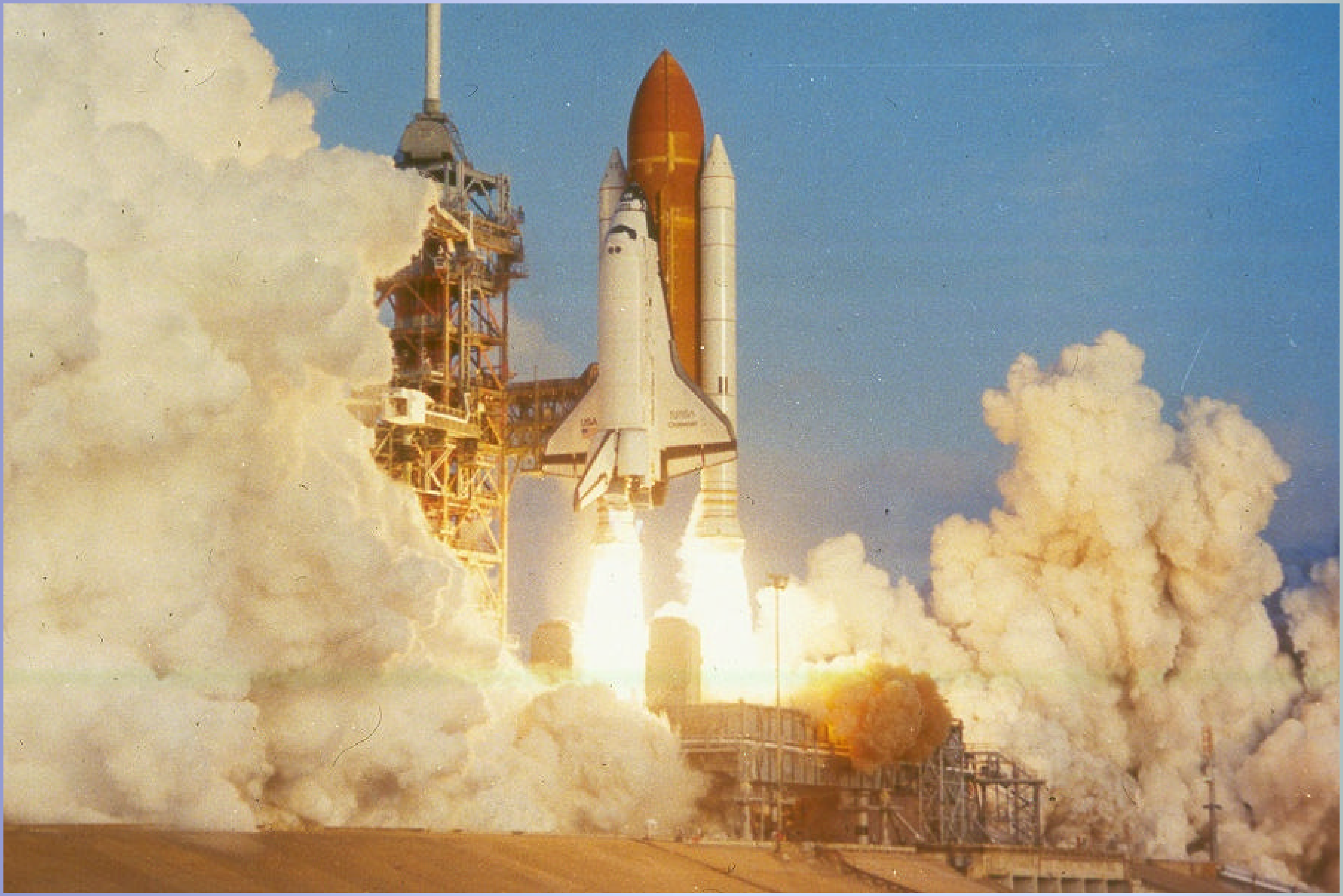
Apollo - Soyuz



Apollo-Soyuz

- Primary mission objective to test rendezvous and docking systems that might be needed during international space rescue missions.
- Second objective was to conduct a program of scientific experiments and technological applications.
- The program lasted for nine days with the 2 spacecraft remained docked for 2 days while the crews exchanged visits.
- During the recovery phase of the U.S. crew was exposed to nitrogen tetroxide from inadvertent firing of the reaction control system during descent. The gases entered the command module through a cabin pressure relief valve that had been opened during the landing sequence.
- All crew members developed chemical pneumonitis following the exposure and required intensive therapy and hospitalization.
- Post flight experiments revealed fatigue anti-gravity muscles following short duration space flight similar to that noted in Skylab.

Shuttle Program



Shuttle Program – ECLSS Systems

ECLSS Functionally Divided Into 4 Systems:

1. Pressure Control System
2. Atmospheric Revitalization System
3. Active Thermal Control System
4. Supply and Waste Water System

Spacecraft Life Support Systems
Shuttle Program

- STS atmosphere maintained at 14.7 PSIA except prior to EVA when pressure is dropped to 10.2 PSIA during preceding ten hours
- STS ECLSS maintains partial pressure of oxygen within 3.2± 0.25 psi (165 mm Hg) - mission rules require oxygen masks be donned if oxygen pressure falls below 2.34 PSIA (121 mm Hg)
- Carbon dioxide concentration is 0.04% on earth - STS ECLSS maintains partial pressure of carbon dioxide at 7.6 mm Hg (0.15 PSIA) if it exceeds 15 mm Hg breathing masks are used
- Water vapor pressure of 10 mm Hg is optimal for habitability and ECS controls water vapor between 6 - 14 torr
- ECLSS maintains ambient temperature within range of 18 – 27^{o} C

Flight Crew Equipment – Shuttle Program

- Crew Clothing/Worn Equipment
- Personal Hygiene Provisions
- Sleeping Provisions
- Exercise Equipment
- Housekeeping Equipment
- Restraints and Mobility Aids
- Stowage Containers
- Shuttle Orbiter Medical System
- Air Sampling System
- Photographic Equipment
- Window Shades and Filters

Medical Operations – Shuttle Program

1. Rigorous medical selection for ASCANS (AMB)
2. Providing full service medical/dental care from the time a crew member is selected.
3. Utilizing preflight, inflight and postflight biomedical data recovery to support health care delivery and extend mission duration.
4. Improve inflight preventive, diagnostic and treatment capabilities for selected medical events.
5. Initiation, maintenance and enhancement of a medically comprehensive environmental monitoring program.
6. Provision of adequate rescue and recovery capability for all phases of flight.

Health Stabilization Program

- Limiting crew exposure the week prior to flight drastically reduced the incidence of inflight illness on STS flights due to common viral URI or flu-like syndromes.
- 7-day timeframe takes care of the majority of commonly prevailing infectious illnesses.
- Only those people designated as primary contacts (PCs) nay come within 6 feet of a crew-member.
- During preflight “quarantine” phase the crew lives in crew quarters at JSC and KSC.

Inflight Medical Capabilities

Objectives:

1. Ensure crew safety and health maintenance during routine operations.
2. Prevent morbidity and mortality from illness/injury.
3. Prevent early mission termination due to medical contingency.
4. Prevent an unnecessary rescue.
5. Increase the probability of success of a necessary rescue.

Crew Medical Officer (CMO) Training:

- 2 crew members designate CMOs
- Training in content of SOMS kit, first aid and management of common medical emergencies in space.

STS SOMS Kits

STS SOMS MBK


MEDICATIONS


F1-5
F1-6
F1-7
F1-8
F1-9
F1-3
F1-10
F1-11
F1-1
F1-2
F1-12
PALLET F1
MEDICATIONS
AND BANDAGE KIT

Inflight Medical Events – STS Program

- 498 of 508 crew members reported experiencing medical events or symptoms during shuttle flight with 1777 separate events reported.
- 433 of 439 men (98.6%) had 1538 medical events.
- 65 of 69 women (94.2%) had 239 medical events.
- Ranges from 0 – 19 medical events per crew member.
- 77 events due to injury, including 7 fatalities.

Epidemiology – STS Program

Longitudinal Study of Astronaut Health

- Monitors the incidence of medical events and provides statistical to the Medical Operations Branch JSC for use in program decision making.
- All astronauts selected by NASA are provided medical care by the JSC Flight Medicine Clinic and followed for life to determine the incidence of medical events.
- Comparison participants have been selected from civil service employees who receive routine annual physicals at the JSC Occupational Health Clinic

Inflight Medical Events

- All medical events and use of medications inflight are recorded and tracked.

Shuttle Program EVA

3 Basic Categories of EVA:

1. Scheduled
2. Unscheduled
3. Contingency

   Suit designed for 7 hour EVA provides environmental protection, mobility, life support and communications.

2 Suits are provided each mission with consumables for up to 3 two person 6 hr EVAs

Space Suit Assembly

- Suit operates at 4.3 PSIA with 100 % oxygen environment
- Total EVA duration of 7 hours consisting of 15 minute egress, 6 hrs EVA, 15 minutes ingress and 30 minute reserve.
- Suit Assembly Consists of the Following:
  - Hard upper torso/arms; lower torso assembly
  - EVA gloves
  - Helmet/EVA visor assembly
  - Liquid cooling and ventilation garment (LCVG)
  - Operational bioinstrumentation system
  - Communications carrier assembly
  - In-suit drink bag
  - Urine Collection device
  - Maximum absorption garment

EVA Life Support Systems – STS ISS

- Suit pressure maintained at 4.3 PSIA (.30 atmospheres)
- EMU maintains suitable partial pressure of oxygen for up to 7 hours
- EMU maintains partial pressure of carbon dioxide at 7.6 mm Hg (0.15 psi) for metabolic rates up to 1,600 BTU/hr and up to 15 mm Hg for higher work rates
- Temperature is regulated using a liquid cooled garment allowing work up to 400 kcal/hr without thermal stress - highest noted is 238/hr in Skylab EVA
- Typical STS EVA is 197 kcal/hr

STS DCS Protocols

Initially Predicted DCS Risk

- 4 hr PBP - 28%
- 10.2 staged PBP - 22-27%

Current Predicted DCS Risk

10.2 staged PBP < 3.6%

- have completed 82 EVA & all but 4 used 10.2 staged PBP (range of 12 to >100 hrs at 10.2 with average of 40 hours)
- no DCS reported

Diagnosis

- Importance of Sx Reporting
- Med Ops C/L
- CMO Hx, P/E with FS support

Treatment

- Return to ambient pressure
- 100% oxygen
- IV fluids & ancillary support
- Suit Pressurization 4.3 psid
- BTA 8.0 psid > ambient
- Deorbit to Hyperbaric Rx Site

STS Environmental Monitoring

- EM seeks to quantify and track all potential biological hazards within the environment.
- All volatile substances and particulates in the air are measured (grab samples) preflight and inflight.
- Particulates pose a health threat: corneal injury, inhalation or ingestion.
- Inflight water samples are also obtained for postflight analysis.
- Between missions orbiter crew compartments a cleaned with a disinfectant solution.

Human Research – ISS Program

- Solicitation:
  - Human research proposals are submitted by investigators in response research announcements that are selected on scientific merit by peer review.
  - Coordinated international research activities ISLSWG
- IRB Review:
  - All proposals involving astronauts and ground based test subjects are reviewed by the IRB at JSC.
- Informed Consent:
  - All crew members participating in life science research are given informed consent and may withdraw as a subject at any time.
- Data Confidentiality:
  - Data sets: Medical Data, Research Data
  - Research Data released in non-attributable manner.

Extended Duration Orbiter Medical Program (1990-1995)

• Missions On Which DSOs/DTOs Flew (STS-32 thru STS-72)	42
• DSOs/DTOs Flown During Program	46
• Average DSOs/DTOs Per Mission	7
• Average Number of Participants Per Mission	5
• Number of Participant Performances	702
• Most DSOs/DTOs On A Mission (STS-50/USML-1)	14
• Number Of Astronaut Participants	133
• Resultant Peer-Reviewed Publications	>95

EDOMP Results

- Cardiovascular control mechanism responses were documented (e.g.**Baroreflex**)
- Documented prevalence of **dysrhythmias** and **blood pressure** norms for short term microgravity exposures (n<10 days)
- Extensive evaluation of post flight **orthostatic hypotension**
    - Decreased plasma volume not totally responsible
    - Decreased total peripheral resistance (TPR) very critical
    - Improved use of anti-gravity suit helpful (preinflation)
    - Liquid cooling garment (LCG) critical to preventing peripheral vasodilatation
    - Lower body negative pressure "soak" treatments of minimal value; overhead associated with protocol outweighs protective benefit
    - Florinef therapy not beneficial; doses which retain significant fluid volume cause recurrence of initial head fullness/congestion associated with early inflight period
    - Improved anti-gravity suit developed but not accepted by crew office; fuller lower torso coverage impeded egress capabilities

EDOMP Results

- Improved isotonic fluid loads developed and verified
- **Total energy requirements** documented to be similar for short duration flight and ground-based normal environment
  - Energy intake decreased in flight; most subjects lose body mass
  - All subjects lose 1-2 liters of total body water
- **Renal stone risk** increased immediately post flight and in flight due to decreased fluid volume intake
- **Functional performance**
  - Aerobic capacity decreased for all subjects (down 10-20%)
  - Protective benefit documented for subjects who exercise at least 3 times weekly for 20 minutes or more at 60-80% preflight maximum work levels
  - Muscle strength decreases documented for legs and trunk (decreased 10-20%)
  - Muscle morphology changes rapidly with decreases in type 1 and type 2 fibers
- **Shuttle environment documented**
  - Volatile organics generally below SMAC levels
  - Necessity for monitoring real-time levels of combustion products led to Combustion Product Analyzer development

EDOMP Results

  - Bacterial levels increase moderately with mission duration
  - Fungal levels generally decrease due to low relative humidity in Shuttle
- **Neurovestibular/neuromuscular function**
  - Effect of flight on neural control of posture was documented
    - Repeat fliers had better performance implying retained learning
    - Two phase recovery (<2 hr; 2-3 days)
  - Normal phased relationship between head pitch and vertical trunk position often breaks down
  - Decreased speed to foveate targets; target acquisition decreased by as much as 1.5 sec post flight
- **Facilities**
  - Crew transport vehicles (CTVs) developed and furnished to DRFC and KSC
    - 568 sq. ft. interior including emergency medical care capability and rest room
  - Medical data collection facilities at both landing sites were improved. A new facility (Postflight Science Support Facility) built at Dryden

EDOMP Results

- KSC facility was modified to permit CTV’s direct interface to second story medical facility
- **Data Archive**
  - Considerable effort was expended to capture and preserve reduced data sets for all research protocol performances
- **Flight hardware**
  - Reentry blood pressure and heart rate monitor developed and verified
  - Collapsible LBNP developed
  - DAS----A generalized controller module was developed to regulate protocols and record data
  - Bar code reader, Heart watch
  - MAS (microbial air sampler), CPA (combustion product analyzer)
  - Formaldehyde monitor
  - Cycle ergometer, ergometer vibration isolation system (EVIS) and passive cycle isolation system (PCIS) developed and tested
  - EDO treadmill---served as prototype for new ISS treadmill

EDOMP Results

- **Flight hardware (cont.)**
  - HOBO temperature monitoring device
  - Echocardiograph system (AERIS)
  - REAGS (improved anti-gravity suit)
  - Saliva collection kit
  - Urine collection kit
  - Breath sample kit
  - Actilume activity monitors
  - Glucometer kit
  - Archival organic sampler (AOS)
  - Visual-Vestibular data system (“Superpocket”)
  - Locker mounted video camera to record egress attempts

Dedicated Spacelab Life Sciences Mission

SLS-1

- Selected in 1978; flew in 1991 (2+ yr delay due to Challenger accident)
- Duration - 10 days
- Subjects - 4 male ; 3 female
- 10 Experiments

SLS-2

- Flew in 1993; primarily repeat of SLS-1 experiments to increase “N”
- Duration - 14 days
- Subjects - 5 male; 2 female
- 8 Experiments

STS-90 Neurolab
(Last Dedicated Spacelab Life Sciences Mission)

Summary of medical events-Russian space flight experience

Mission	Launch date	Crew	Duration	Remarks
Vostok 1	April 12,1961	Gagarin	1hr 48min.	First human space flight
Vostok 2	July 21,1961	Titov	1d 1hr 18min.	First reports of space motion sickness
Voskhod 2	March 18, 1965	Belyayev Leonov	1d 2 hrs 2 min.	First EVA visor fogging not reported
Soyuz 1	April 23,1967	Komarov	1d 45 min.	Parachute system failed first space flight casualty
Soyuz 11-Salyut 1	June 6, 1971	Dobrovolskiy Volkov Patsayev	23d 18hrs 2 min.	First space station; reentry sudden depressurization caused death of crew members
Soyuz-18a	April 5, 1975	Lazarev Makarov	21 min.	Mission to Salyut-4 aborted, third stage failure crew experiences up to 20 G. with minor injuries

Summary of medical events-Russian space flight experience

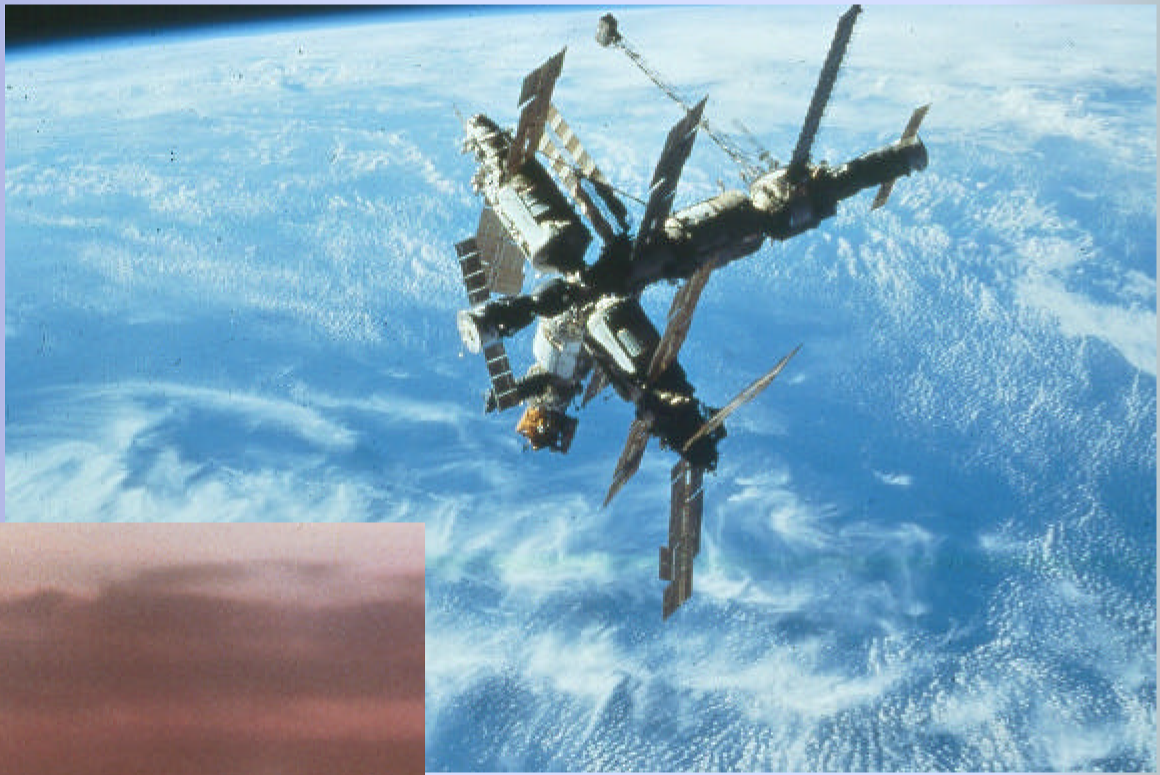
Mission	Launch date	Crew	Duration	Remarks
Soyuz 18 – Salyut 4	May 24,1975	Klimuk Sevatsyanov	63d 23 hrs 31 min.	First use of oral saline as countermeasure for OI
Soyuz 21 – Salyut 5	July 6, 1976	Volynov Zholobov	49d 6h 24 min.	Early return of crew due to crewmember headaches
Soyuz 26 – Salyut 6	December 9, 1977	Romanenko Grechko	96d 9h 59 min.	Significant CV deconditioning postflight due to poor compliance with countermeasures
Soyuz 32 – Salyut 76	February 25, 1979	Lyakhov Ryumin	175d 36min	Recurrent vestibular symptoms on orbit and postflight
Soyuz T4-Salyut 6	March 12, 1981	Kovalenok Savinykh	74d 18hr 38 min.	Significant postflight vestibular distrubances
Soyuz T5 – Salyut 7	May 13,1982	Berezovoy Lebedev	211d 8hr 25 min.	Reported renal colic possible urolithiasis, no mission impact

Summary of medical events-Russian space flight experience

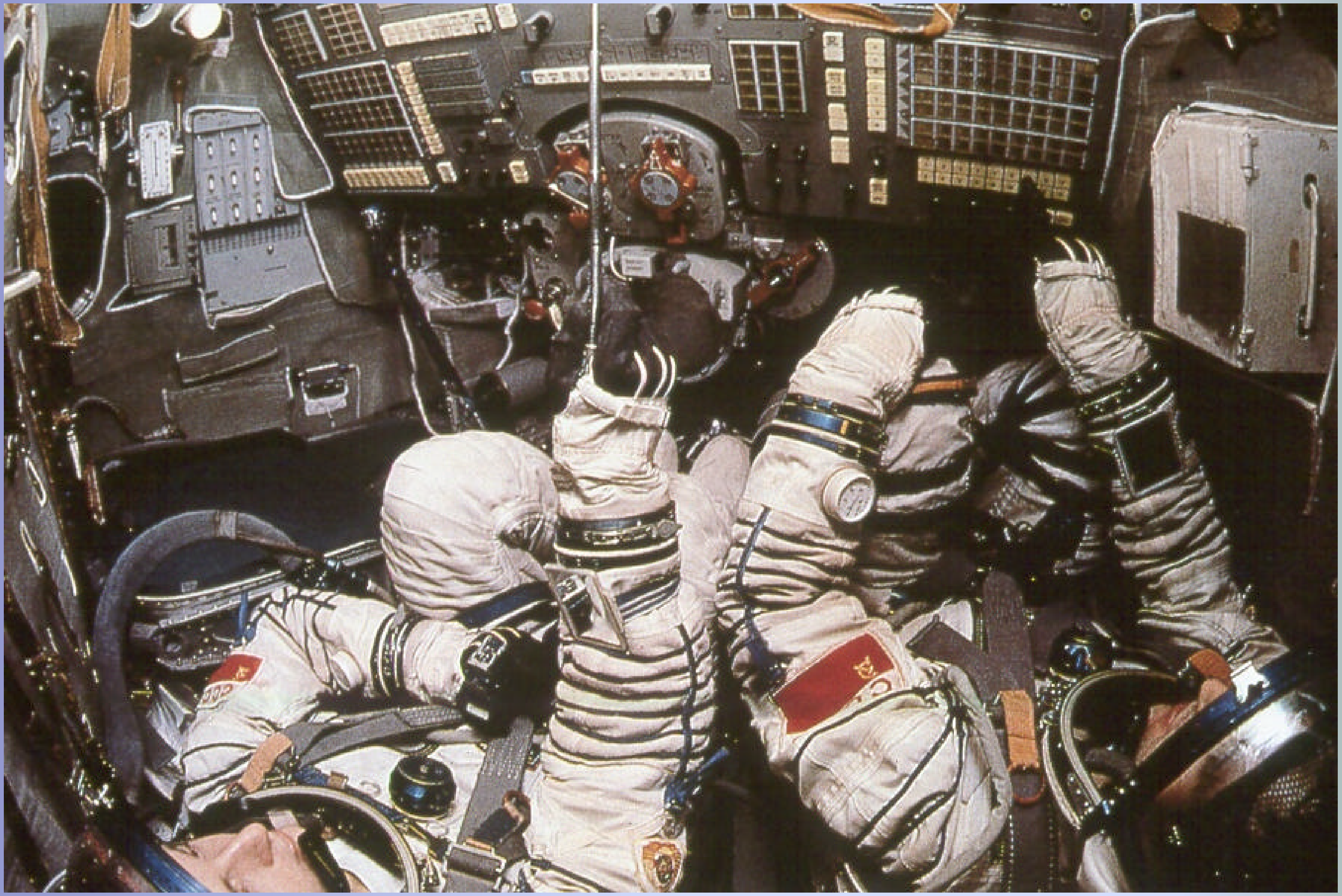
Mission	Launch date	Crew	Duration	Remarks
Soyuz	Sept. 27,1983	Titov Strekalov		Explosion 90sec before launch, LES activated, 17G, unharmed
Soyuz TM2 – MIR	Feb. 6,1987	Romanenko Laveikin	326d 11h 174d 2h	Laveikin returned early following cardiac dysrhythmia
Soyuz TM10 - MIR	August 1,1990	Manakov Strekalov	130d 36 min	Crewmember exhibited URI, EVA delayed until recovery

Adapted from: Nicogossian, A.E., C.L. Huntoon and S. Pool Space Physiology and Medicine, 1994

Phase 1 MIR Program



Soyuz



Phase 1 Program

Four Main Objectives:

1. Learn how to work with international partners.
2. Reduce risks associated with developing and assembling a space station.
3. Gain operational experience for NASA on long-duration missions.
4. Conduct life science, microgravity and environmental research programs.

Phase 1 Program Provided:

1. Missions of Russian cosmonauts aboard the Space Shuttle.
2. Long-duration missions of American astronauts aboard MIR.
3. Space Shuttle and MIR joint space missions with rendezvous and dockings, during which a NASA astronaut was rotated into the crew of the basic expeditions aboard MIR.

NASA-Mir Flight Program

- 8 flights between 1995-1998
- 9 Shuttle missions supported program
- 23 potential long-duration subjects
  - 7 astronauts (6 male; 1 female)
- Average flight duration - 131 days or 19 weeks
- Phase 1A (1995-1996)
  - 25 experiments
  - 8 subjects (max) including Cosmonauts
- Phase 1B (1996-1998)
  - 26 experiments
  - 15 subjects (max) including Cosmonauts

Joint RSA/NASA Selection - AMERD

- Clear understanding of the problems of medical ethics in both countries as well as population differences.
- Better understanding by the American medical specialists of the physical and psychological factors characteristic of long duration spaceflight, including launch and reentry aboard the Soyuz TM spacecraft (selection issues).
- Establishment of lines of communication among medical specialists of U.S. organizations and organizations of the Russian Ministry of Defense and Ministry of Public Health

Astronaut Biomedical Training

- Fundamentals of aerospace medicine.
- Medical health monitoring and examination.
- Physical training.
- Medical tests, studies and exercises.
- Preparation for joint activities.
- Biomedical training to ensure compliance with physical conditioning, good functional psychophysiological capabilities of the body and a high level of performance.

Astronaut Biomedical Training

- Preserve and improve health, maintain high level of fitness and keep the body in good condition.
- Organize and conduct investigations and training to maintain level of stabilization in exposure to spaceflight factors.
- Know health monitoring procedures
- Use onboard countermeasures
- Operate life support systems of a specific crewed spacecraft.
- Use onboard sanitary, epidemiological and radiation protection measures.
- Acquire skills in disease diagnostics and using onboard medical supplies and countermeasures.

MIR Defibrillator

- Zoll Defibrillator transcutaneous pacing unit
- Self-adhesive electrodes
- ACLS Medication Kit
- English/Russian protocols
- CMO training

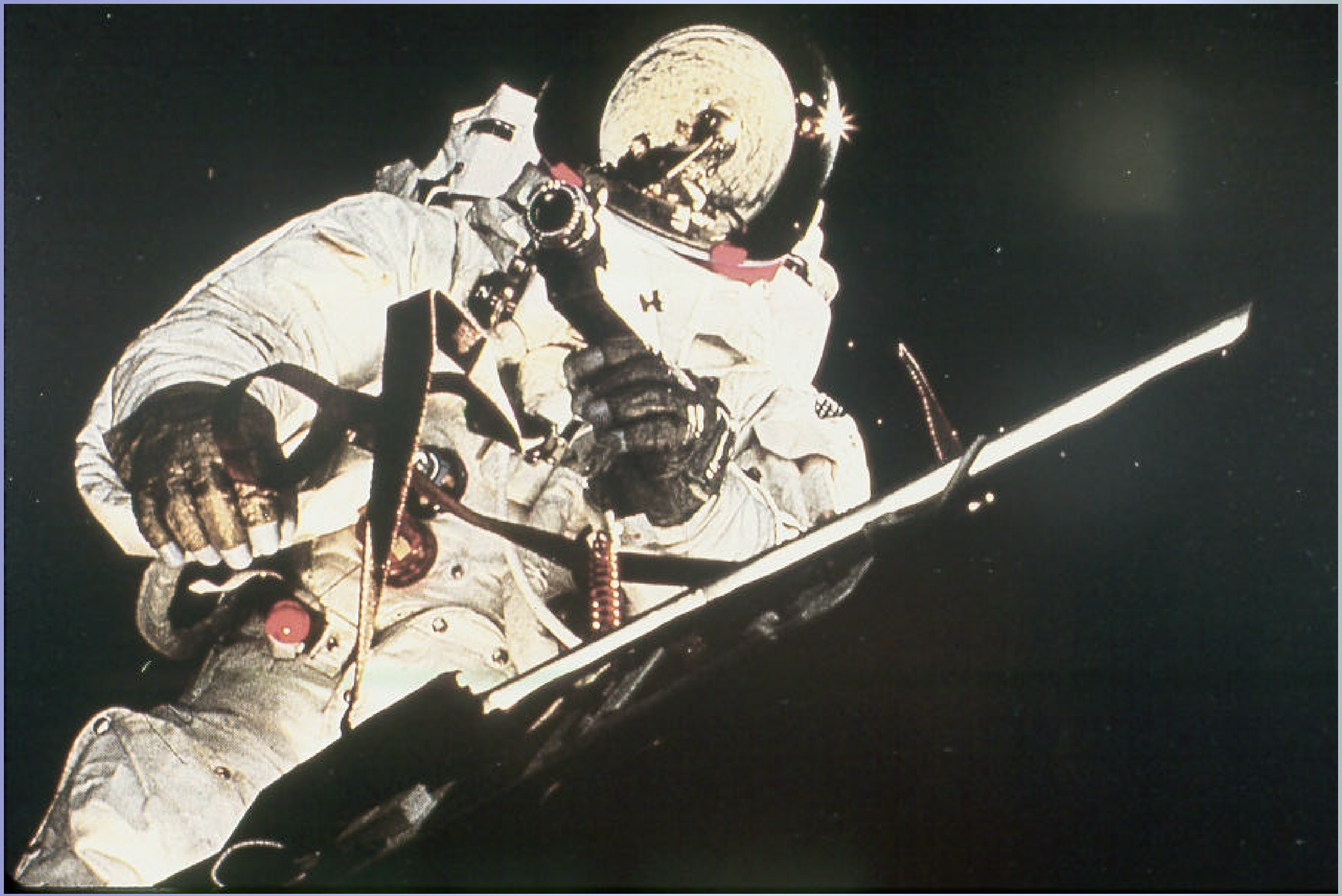
Phase 1 Mir Experience

- The US astronauts were "guests" on the Russian Mir
- We agreed to utilize their systems to a major extent
  - Countermeasures
  - Food (shared)
  - Habitability
  - Environmental Health Systems
  - Medical Evaluation (shared)
- A major objective was to observe and learn from their long-duration experience base
- This was accomplished
- Several problem/risk areas were identified
  - Russian countermeasures were not effective to the extent required

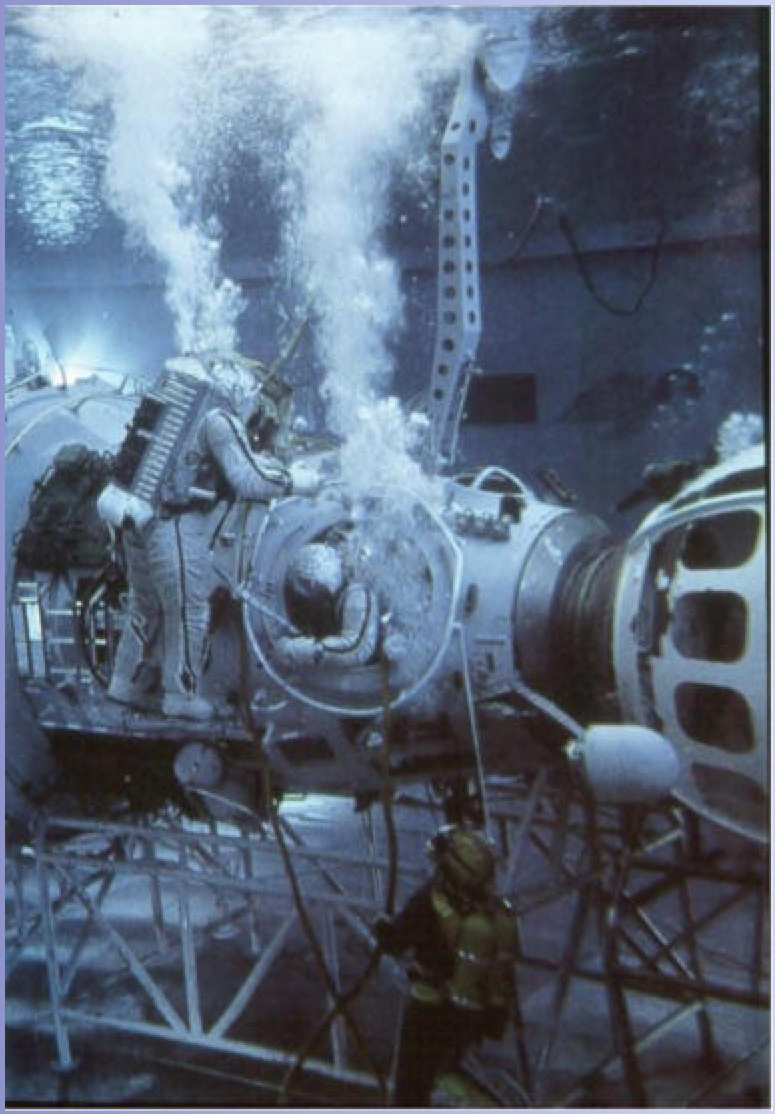
Significant Medical Events-MIR Phase 1

- Infections
- Urinary retention and incontinence
- Kidney stone
- Arrhythmias
  - Severe enough to cancel important planned activities
- Thermal injury
- Behavioral psychological depression/Anxiety reactions
- Eye injury
- Dental problems
- Severe skin rashes
- Severe back pain
- Temporary hearing threshold shifts (Mir)

MIR EVA Program



EVA Training - Hydrolab



- Hydrolab facilities reviewed and certified by NASA
- Hyperbaric capability
- ACLS capability with NASA supplied personnel
- English/Russian protocols

MIR DCS Protocols

Initially Predicted DCS Risk

26% risk of DCS

Have completed 900 suited chamber trials and have not observed DCS

Use 30 min PBP with 100% O2

- Have not observed DCS on-orbit
- MIR often < 14.7 typically from 12.2 to 13.0 PSIA
- Orlan suit at 5.8 PSIA with additional protective effect from suit rigidity

Diagnosis

Importance of Sx Reporting

Hx, P/E with FS support

Treatment

Return to ambient pressure

oxygen

Mir Countermeasures

- Pre-flight
  - Training on exercise equipment like that to be used in-flight
  - Lower Body Negative Pressure system training and baseline
  - Rotating Chair Training*
  - Survival Training
  - Controlled and Monitored Exercise Required
  - Crew Medical Officer training
  - Centrifuge training
  - EVA and altitude chamber training
  - 0g orientation in Aleutian aircraft

* US crewmembers did not participate

Mir Countermeasures

- In-flight
    - Treadmill
    - Bicycle ergometer
    - Resistive Exercise (Bungee Cords)
    - LBNP* (Lucid did for research)
    - Vitamins*
    - Psychological Support
    - Medical Conferences
    - U.S. and Russian medical kits available & used
    - Anti-G Suit for entry
    - Penguin Flight Loading Suit (selected usage by Cosmonauts and Astronauts)
    - Special Earphones to protect hearing
    - Pharmacological Rx prior to return*
    - Kantever lack-up stockings for use in entry

Mir Countermeasures

- Post-flight
  - Landing
    - Assisted egress often required
    - Adequate rest period planned
    - Assisted living at landing site
  - Early active Rehabilitation (R+3 to R+14)
    - Clinical monitoring; “live in physician” until stable
    - Careful reambulation and limited exercise (swimming)
    - If able, walking, jogging, biking, and stairmaster
    - Resistive, weight training when able
  - Ongoing Rehabilitation: (R+14 to R+45)
    - Increased physical training, aerobic, anaerobic, strength, and coordination
    - Clinical monitoring as required

Mir Countermeasure Assessment

- Neither Russian or US re-habilitation adequate to permit return to normal activities rapidly
  - Return to duties involving flying no sooner than four weeks minimum in some cases longer based on clinical judgement
- Often difficult for crewmembers to comply with countermeasure Rx
  - Two fires, loss of cabin pressure, nonstandard atmosphere, toxic CO exposure, cabin temperature too high for exercise, work-rest cycle over subscribed
- Routine post-flight weakness, marked loss of muscle strength, and muscle atrophy observed in all crewmembers
- Ataxia and poor coordination post-flight

Mir Countermeasure Assessment

- Marked loss of Ca from weight bearing portions of skeleton, some regional losses > 2 standard deviations from normal
- Risk of renal stone formation
- Marked immediate post-flight orthostatic intolerance
- Based on cardiovascular,data, it is contra-indicated to return Mir crewmembers sitting up, recumbent seating required
- Aerobic capacity reduced
- Significant arrhythmia observed
- Depression & anxiety reactions observed and treated
- Marked weight loss observed
- Mir countermeasures were not effective in mitigating risks
  - Contrary to Russian claims

Mir Program Post-flight

MIR Program Post-flight

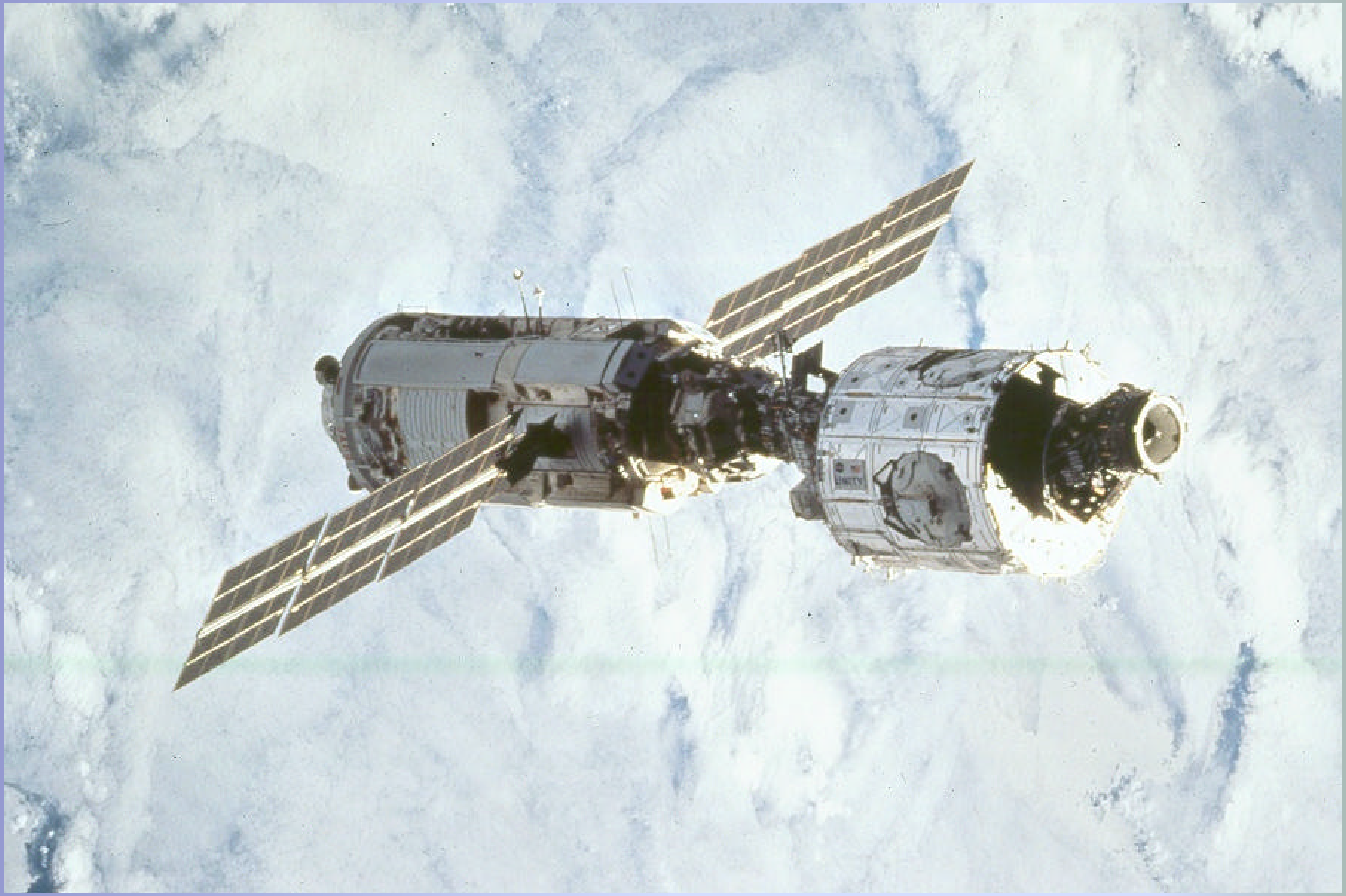
Phase 1 - MIR Program

- Observations:
  - Humans are very adaptable and can overcome many of the multiple challenges associated with space flight.
  - The publicly available safety and health record of human related considerations of space flight has generated a perception of a non-issue.
- Misperceptions:
  - We have never had life-threatening medical events associated with otherwise successful space flights.
  - The risks associated with human considerations of space flight are acceptable and need no further study or mitigation.

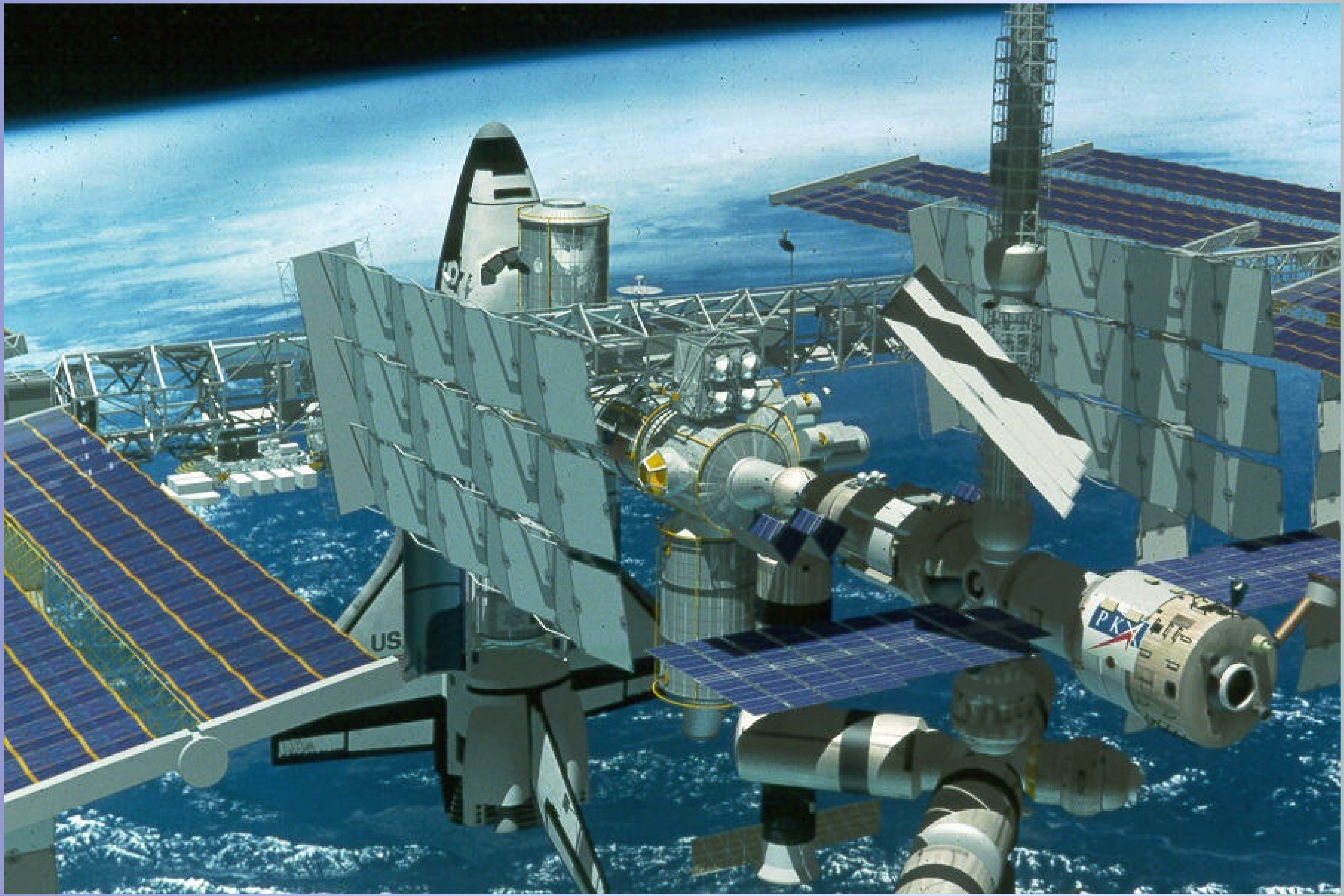
Perception Issue - Reality

Mir Experience			G	No/Minimal Risks
			Y	Significant Risks
Habitation/Environmental Health Systems			R	Potential Life-threatening Risks
Atmospheric Pressure/Composition	R			
Atmosopheric Sensors	Y			
Clothing Systems	G			
EVA Systems	Y			
Food Systems	Y			
Habitability	Y			
Microbiology	G/Y			
Thermal Environment	Y			
Toxicology	R			
Waste Management	Y			
Adaptation/Countermeasures				
Bone Demineralization	Y			
Cardiovascular Alterations	R			
Exercise & nutrition	Y			
Human Performance	Y			
Immunology, Infection, Hematology	R			
Muscle Atrophy	Y			
Neurovestibular Adaptation	Y			
Neurobehavioral & psychosocial health	R			
Radiation Effects	Y			
Health Care				
Preventative Care	Y/R			
Diagnostics	Y/R			
Therapeutics	Y/R			

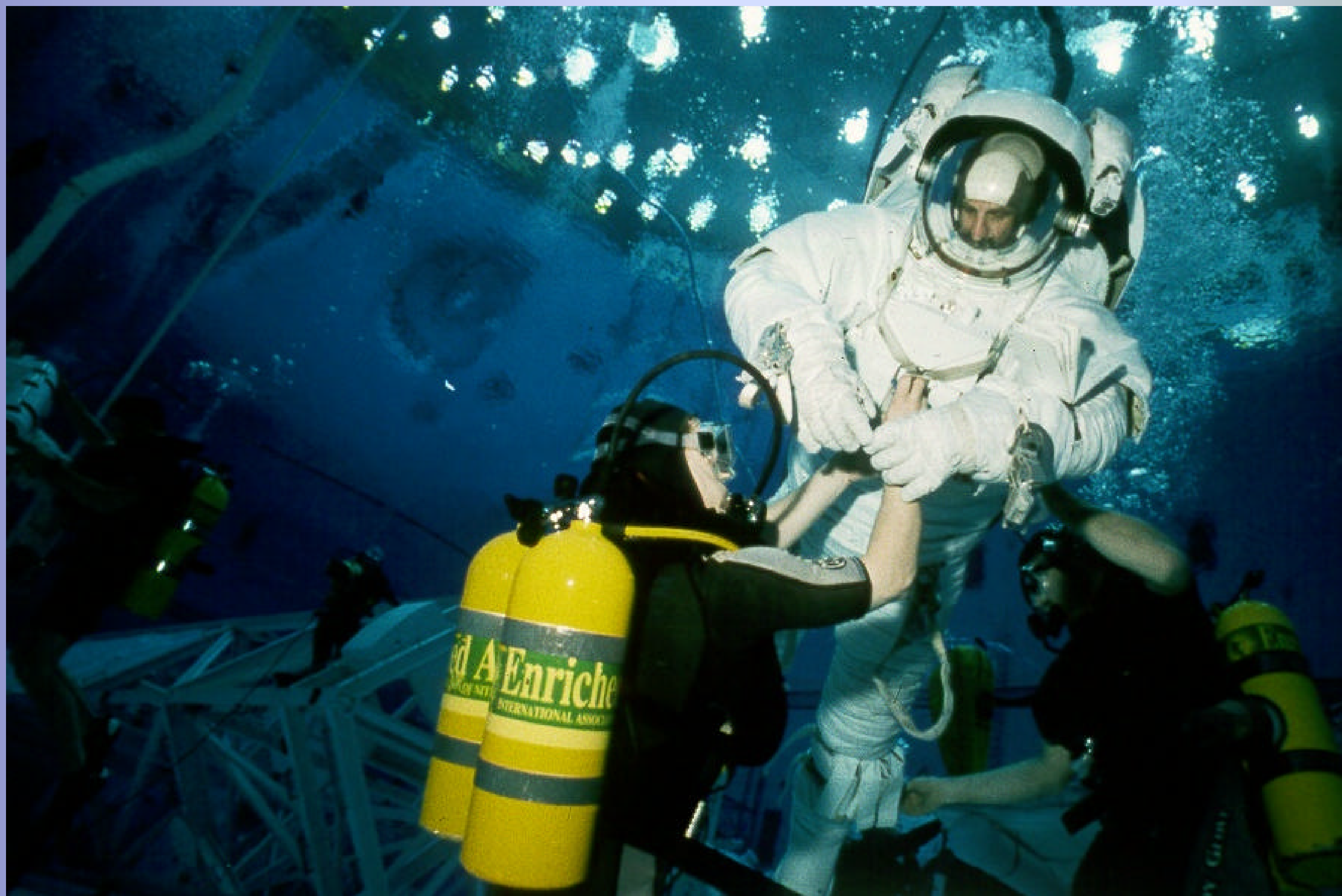
International Space Station



International Space Station



ISS Training - EVA Training at NBL



ISS Training - KC-135 Microgravity Flights

ISS Training - Analogue Environments

NASA Medical Operations
ISS Program

- Rigorous Medical Selection: EXCAN Training, AMERD
- Comprehensive preflight training program to optimize performance.
- Health Stabilization Program.
- Family Support Office: preflight, inflight and postflight.
- Crew Medical Officer Training.
- Inflight Medical Care: HMF, CHeCs.
- Assured Crew Return: Soyuz, ACRV.
- Postflight Rehabilitation Program.

International Medical Operations ISS Program

- Multinational Medical Operations Panel (MMOP)
  - Series of working groups that review ISS medical and habitability issues.
- Multinational Space Medicine Board (MSMB)
  - AMERD used as governing document for standardized selection of international crew members for ISS.
- Multinational Medical Policy Board (MMPB)
  - International group to develop medical policies for ISS program.
- Human Research Multilateral Review Board (HRMRB)
  - International IRB to review the all ISS experiments involving human subjects both inflight and terrestrial to ensure the safety and health of all participants in human research.

International Medical Operations
ISS Program

Issues	Activity
Prevention	Robust Selection Preflight Preparation Countermeasures (CEVP)
Diagnosis	CMO Training CCCDP
Treatment 1. Resuscitation 2. Inflight Clinical Care 3. Stabilization/Transport 4. Definitive Care	CMO Training CCCDP

Implementation of Countermeasures

Countermeasures Program

- Fluid/salt loading
- Pharmacological
- Exercise
- Nutritional
- Environmental
- Mechanical
- Special training

Habitability Issues – ISS Program

- Cabin Atmosphere
- Toxicology
- Acoustics
- Radiation
- Flight Crew Equipment:
  - Clothing, sleep quarters, exercise equipment, food, family support, behavioral support.
- Clinical Capability

ISS EVA Program

ISS EVA Risk

Risk of DCS related to the incidence of DCS with a given PBP and the number of exposures of crew members to the EVA environment (wall of EVA - 484)

It is likely that DCS will occur at some point during ISS and the possibility of severe Type 2 case exists

Family of PBP:

- Available
  - 4 hr 100% O_2 has 28% DCS Risk
  - Campout has 1.2 - 9% DCS Risk
  - 2 hr PBP has 1.2 - 2.3% DCS Risk
- Not Yet Available
  - 90 minute PBP

ISS EVA Protocols

Initially Predicted DCS Risk
- 4 hr PBP - 28%
- Campout - 1.2 - 9%
- 2 Hr PBP - 1.2 - 2.3%

Incidence of:

Grade IV VGE	?
Type 1 DCS	?
Type 2 DCS	?

Diagnosis
- Importance of Sx Reporting
- New cuff checklist
- CMO augmented training in Hx & P/E with NIDB
- EVA DCS Examination scorecard
- Augmented FS training

Treatment
- Return to ambient pressure
- 100% oxygen
- IV fluids & ancillary support
- Suit Pressurization 4.3 PSID
- BTA 8.0 PSID > ambient
- Hyperbaric Therapy

ISS Program – Medical Operations

Probability of Occurrence

	Minor	Severe
High	Class 1	Class 2
Low		Class 3

Severity of Illness/Injury

Medical Risks – ISS Program

CLASS I

- ***mild symptomatology***
- ***minimal effect on performance***
- ***not life threatening***

EXAMPLES

- ***URI***
- ***Small Laceration***
- ***Headache***
- ***SAS***

MISSION IMPACT: Minimal

Medical Risks – ISS Program

CLASS II

- *moderate to severe symptomatology*
- *significant effect on performance*
- *potentially life threatening*

EXAMPLES

- *DCS*
- *Nephrolithiasis*
- *Appendicitis*
- *Ulcers/GI Bleed*
- *Abscess formation*
- *Cardiac dysrhythmia*
- *Sinusitis*
- *Trauma*

MISSION IMPACT: Requires significant inflight capability to prevent mission termination and assured crew return where appropriate.

Medical Risks – ISS Program

CLASS III

- ***immediate severe symptomatology***
- ***acutely life threatening - possibly sudden death***
- ***requires immediate resuscitation capability***

EXAMPLES

- ***DCS***
- ***Cardiac dysrhythmia***
- ***Electrocution***
- ***Septic Shock***
- ***Anaphylactic shock***
- ***Hypovolemic shock***
- ***Dysbaric air embolus***
- ***Trauma***

MISSION IMPACT: Requires significant inflight capability for resuscitation and assured crew return to definitive care facility

Inflight Care – Emergent Crew Return

- Worst case - complete program interruption
  - It is estimated that the incapacitation of a single crew-member causing an ISS increment to be terminated could be over $500 M in total program costs (utilization of crew return capability, additional Shuttle flights, disruption/cancellation of science program elements, re-programming of ground processing)
- Mid-level scenario - major program disruption
  - It is estimated that the inability of one or more crew members to fulfill their mission assignments (e.g., 25% reduction in 2 crewmembers) could cost the program between $25 to $50 M - reduced science production and the overall re-scheduling in future increments to make up the deficit.
- Long-term scenario - increased efficiency and longer crew stays
  - It is estimated that the program could begin savings of $25 to 50 M/year (by 2006) through increasing stay times from 3 to 6 months and by increased efficiency of operations (e.g., shorter exercise countermeasure times).

ISS Risk Mitigation - Defining Risk

Exposure to the space environment resulting in dysfunctional physiological/behavioral adaptation, injury or loss of life-- as a function of...

- Probability of occurrence of an undesired event within a stated period of time
- Resulting severity of harm, or illness/disorder
- Uncertainties associated with probability and severity
- Cumulative effects of exposures

What Risks are Considered?

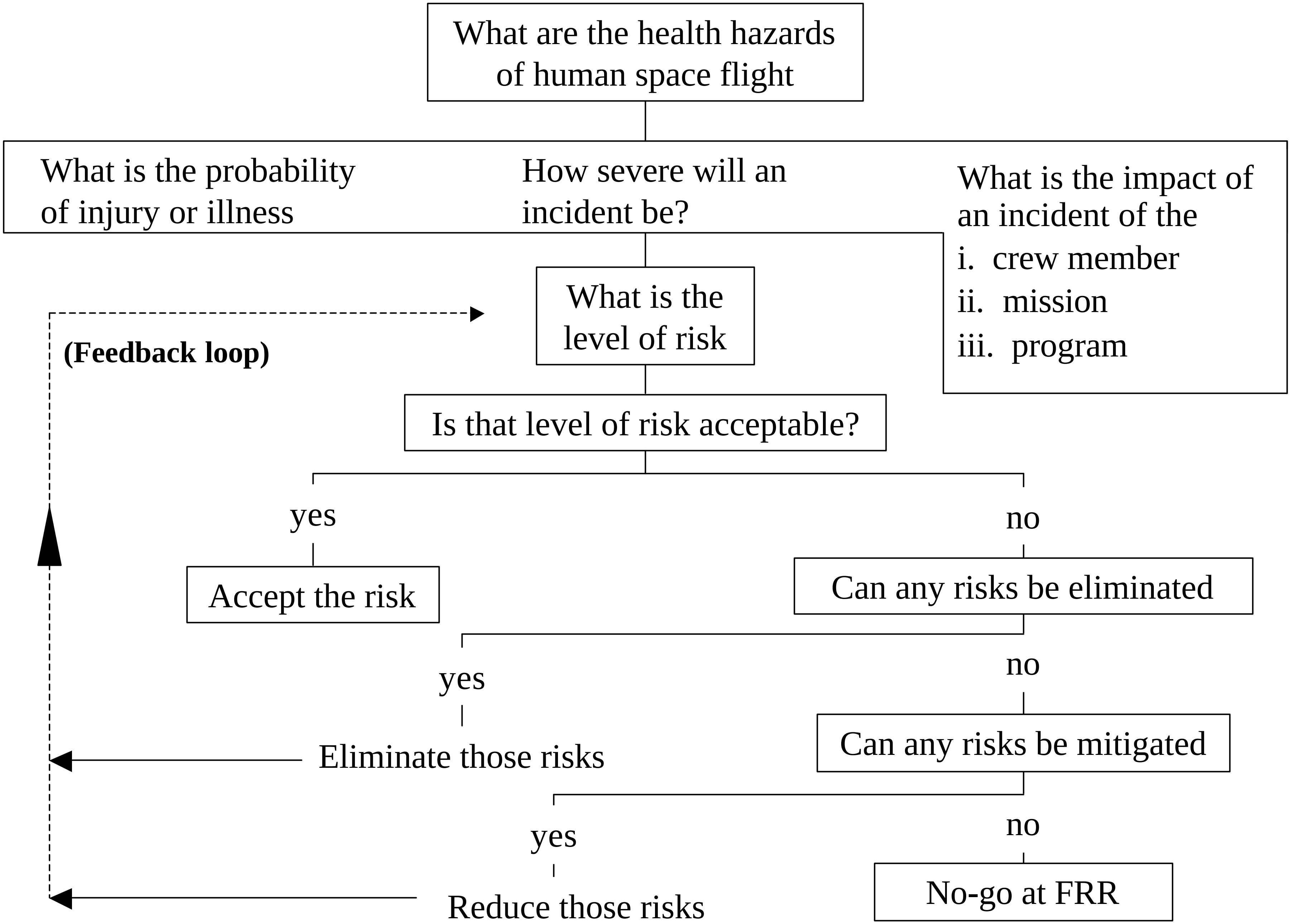
Risks which are applicable to crew members are those which result in...

- Post-flight debilitation
- Prolonged re-habilitation post-flight
- Decreased crew performance during mission operations
- Decreased performance during descent and egress
- Negative behavioral changes
- Mission associated minor impairment, illness or injury
- Crew rescue required due to risk of severe illness or injury
- Crew rescue required due to risk to life
- Mission failure
- Death of a crewmember

Consequences of Risk

- General Crew Health
  - Difficult readaptation to 1g environment
  - Prolonged periods between flight readiness for individual crewmembers
  - Acute or long-term health consequences
- Crew operational impact
  - Loss of productive time
  - Illness
  - Injury
  - Death
- Mission Impact
  - Postponement
  - Interruption
  - Loss of mission objective(s)
  - Failure
- Program Impact
  - Program disruption/stand-down
  - Loss of program objectives
  - Decreased program effectiveness

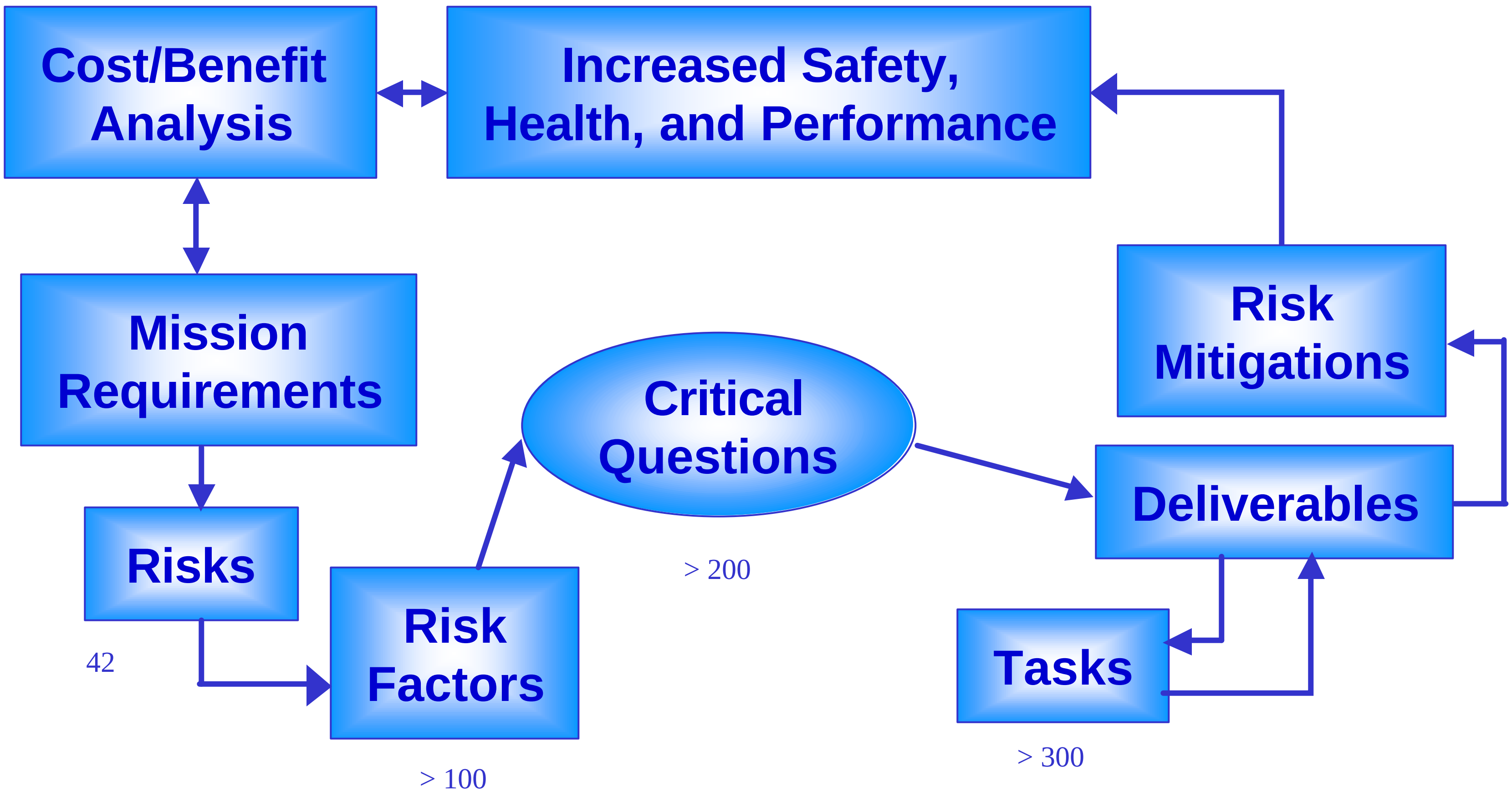
Risk Management Logic



Critical Path Roadmap Project

The Critical Path Roadmap Project (CPRP) is an integrated, cross-disciplinary strategy to assess, understand, mitigate, and manage the risks associated with long-term exposure to the space environment within overall resource considerations

CPRP & Risk Management



Risk Areas

Biomedical activity was divided into 11 Discipline Risk Areas to provide the structure under which we operate

Advanced Life Support

Bone Loss

Cardiovascular Alterations

Environmental Health

Food and Nutrition

Human Performance

Immunology, Infection & Hematology

Muscle Alterations & Atrophy

Neurovestibular Adaptation

Radiation Effects

Clinical Capability

CPRP Risk Type Summary

- 1999: 42* identified risks for which we lack validated countermeasures
- 2006: countermeasures identified for 21 of original 42 risks
- 2010: countermeasures identified for all 42 risks

** does not include risks for which countermeasures already exist - also 9 additional risks that have not been cross-prioritized*

1999 / 2006 / 2010	*Demonstrated problem*	*Potential problem*
No countermeasures	Type I Risks **4 2 0**	Type II Risks **5 2 0**
No ground-verified countermeasures	Type II Risks **4 2 0**	Type III Risks **12 6 0**
No flight-validated countermeasures	Type III Risks **6 3 0**	Type III Risks **11 6 0**
Countermeasures	Type IV Risks existing + **21** + **42**	N/A

Countermeasures - Deliverables

- Effective and efficient countermeasures that mitigate the deleterious effects of human space flight
  - Radiation
  - Bone loss
  - Muscle strength loss
  - Psycho-social
  - Cardiovascular deconditioning
  - Neurovestibular
  - Immunological
- Artificial gravity approaches
- Integrated/optimized ground/flight research program
- Digital Human

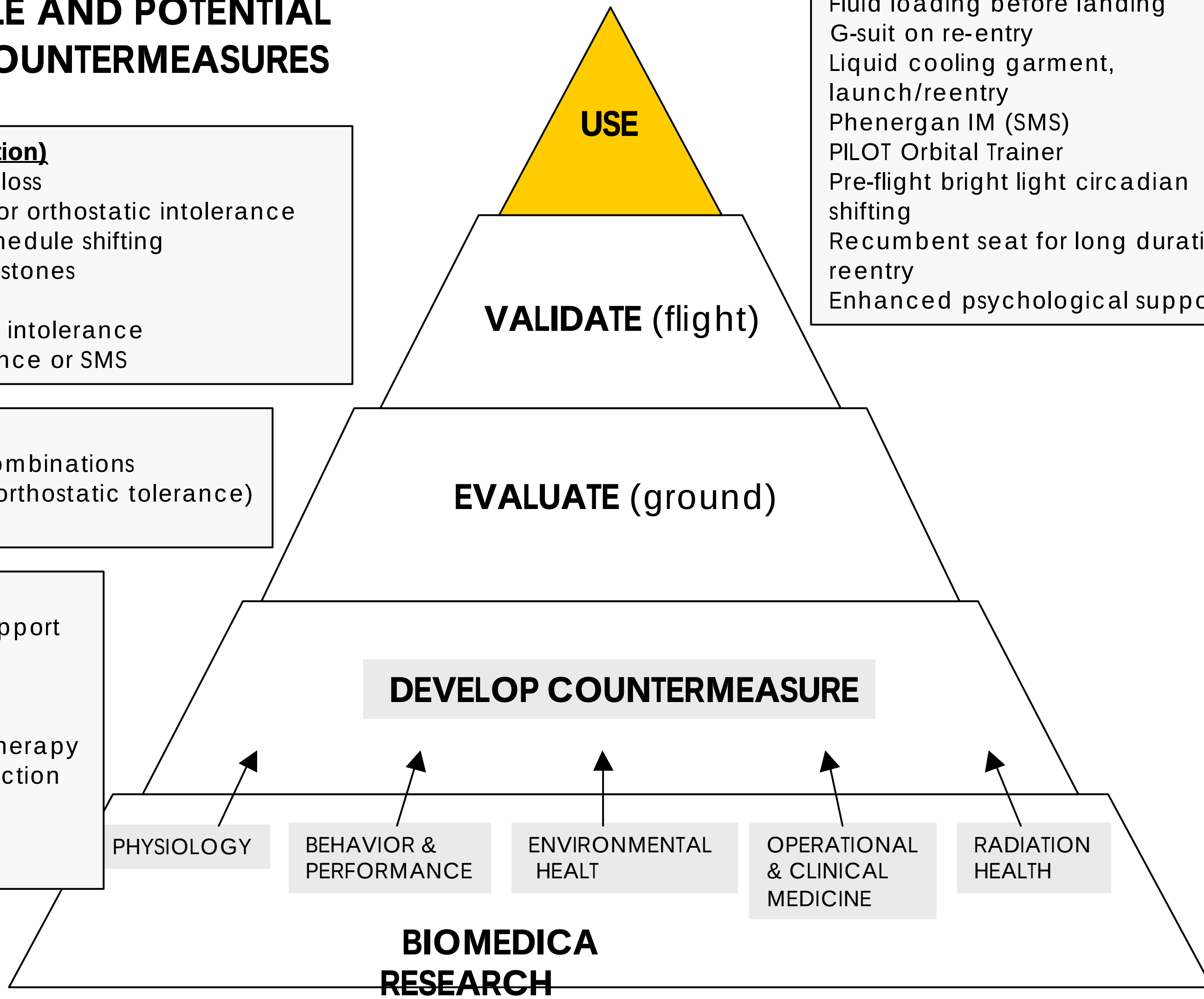
AVAILABLE AND POTENTIAL COUNTERMEASURES

IMPLEMENTED
Aerobic exercise
Fluid loading before landing
G-suit on re-entry
Liquid cooling garment, launch/reentry
Phenergan IM (SMS)
PILOT Orbital Trainer
Pre-flight bright light circadian shifting
Recumbent seat for long duration reentry
Enhanced psychological support

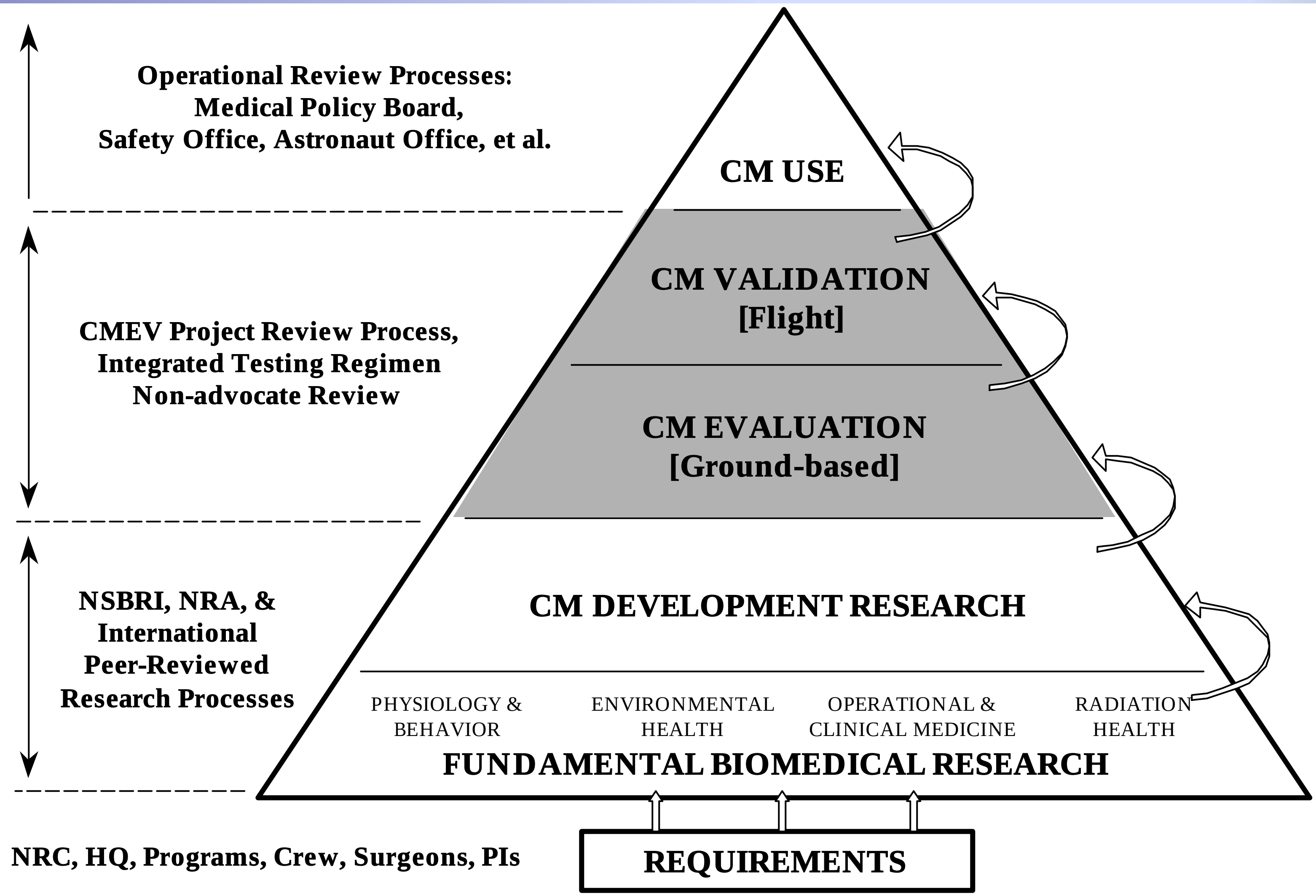
MATURE (ready for evaluation)
Bisphosphonates for bone loss
Maximum exercise bouts for orthostatic intolerance
Light exposure for work schedule shifting
Potassium citrate for renal stones
Prebreath for EVA
Skin cooling for orthostatic intolerance
AFT for orthostatic intolerance or SMS

MID-DEVELOPMENT
Growth factor/exercise combinations
Pharmacologic (Improve orthostatic tolerance)
Resistive Exercise (type)

EARLY DEVELOPMENT
Behavior/Performance Support
Biotechnology
Genetic Engineering
Gravity Replacement
Hormone Replacement Therapy
Immune Deficiency Correction
Nutrition
Radiation Protectants
Rotation for Equilibrium



Countermeasure - Life Cycle



Countermeasure Readiness Levels

BASIC RESEARCH

RESEARCH TO PROVE FEASIBILITY

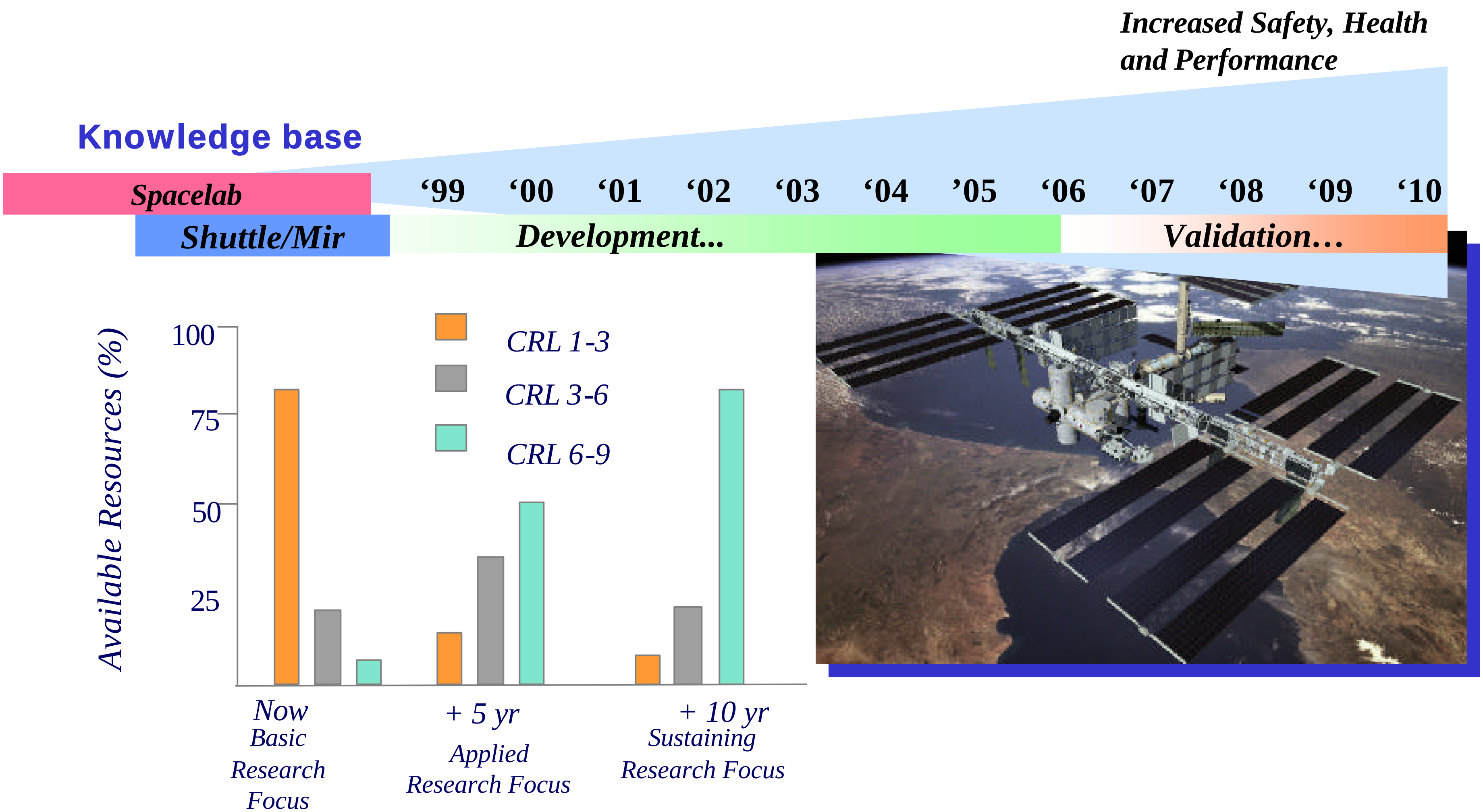
COUNTERMEASURE DEVELOPMENT

COUNTERMEASURE DEMONSTRATION

COUNTERMEASURE OPERATIONS

1. PHENOMENON OBSERVED AND REPORTED. PROBLEM DEFINED
2. HYPOTHESIS FORMED, PRELIMINARY STUDIES TO DEFINE PARAMETERS. DEMONSTRATE FEASIBILITY.
3. VALDIDATED HYPOTHESIS. UNDERSTANDING OF SCIENTIFIC PROCESSES UNDERLYING PROBLEM.
4. FORMULATION OF COUNTERMEASURES CONCEPT BASED ON UNDERSTANDING OF PHENOMENON.
5. PROOF OF CONCEPT TESTING AND INITIAL DEMONSTRATION OF FEASIBILITY AND EFFICACY.
6. LABORATORY/CLINICAL TESTING OF POTENTIAL COUNTERMEASURE IN HUMAN SUBJECTS TO DEMONSTATE EFFICACY OF CONCEPT.
7. EVALUATION WITH HUMAN SUBJECTS IN CONTROLLED LABORATORY CONDITIONS SIMULATING OPERATIONAL SPACE FLIGHT ENVIRONMENT.
8. VALIDATION WITH HUMAN SUBJECTS IN ACTUAL OPERATIONAL SPACE FLIGHT TO DEMONSTRATE EFFICACY AND OPERATIONAL FEASIBILITY.
9. COUNTERMEASURE FULLY FLIGHT TESTED AND READY FOR OPERATIONAL IMPLEMENTATION.

Ensuring Safety and Productivity on ISS



Health Care Systems

Overview

- Provide quality and comprehensive health care throughout all mission phases
- Proper health care aims to
  - maximize safety
  - optimize performance
  - prevent long-term negative health consequences
- Optimum health care systems strive to be
  - economic
  - light-weight
  - compact
  - autonomous
  - low-maintenance
  - minimally invasive

Goals

- Provide medical care which has been adapted for autonomous space travel
- A database of clinical norms for medical care in microgravity and reduced-gravity environments
- Cybernetically-assisted surgical environment for real-time care rendering in space flight and virtual training activities

Health Care Systems - Deliverables

- Preventative health care systems focused on pre-flight conditioning
- Accurate, low-power, low-weight, reduced volume, efficient diagnostic systems capable of detecting abnormal human function across all body systems
- Efficient health care systems capable of therapeutic intervention for a wide range of pathological and trauma scenarios

CPRP Summary

- Assessed, integrated, and prioritized risks
- Communicating results
- Establishing web site for wide distribution to scientific community
- Mapping critical path to current program, issues, and recommendations of CSBM strategies report
- Developing areas for focused research projects & providing input to NRA process
- Will serve as the basis and overall metric to understand and demonstrate progress of the Bioastronautics program

National Space Biomedical Research Institute

- Initially formed 1997 with 7 consortium members:

  Harvard, Johns Hopkins, Baylor, Rice University, Moorehouse School of Medicine, MIT, Texas A&M

- 8 teams:

  1. Technology & development
  2. Radiation
  3. Bone loss
  4. Neurovestibular
  5. Cardiovascular alterations
  6. Human performance, sleep and chronobiology
  7. Immunology, infectious diseases and hematology
  8. Muscle alterations & atrophy

Current Activities with NSBRI

Integration Strategy of Overall Program

- Initiation of Integrated Research Team
- Coordination/management of Critical Path Roadmap Plan
- Standardized crew data collection
- Current space biomedical data evaluation and consolidation
- Space asset coordination

Expansion of Extramural Community Participation

- Development of approach for expansion of inter-agency and NSBRI joint activities
- Development of concept for a Space Biomedical Research Training and Data Center located at or near the Johnson Space Center
- Expansion of the NSBRI education and outreach program, consistent with the projected growth of the Institute

Restructuring of the Joint NASA/NSBRI Discipline Teams

- Identify and initiate new teams
- Plan for NSBRI to assume leadership role in appropriate joint teams

Expansion of NSBRI

Other Expansion of the NSBRI

- Consortium and institutional membership growth
  - University of Washington
  - Brookhaven
  - University of Pennsylvania
  - Mount Sinai University
  - University of Arkansas
- Development of graduate and post-doctoral training programs
- Growth of the NSBRI core research program, leading to an expansion of the number of tasks per research area
  - Neurobehavioural and Psychosocial
  - Nutrition
  - Physical Fitness and Rehabilitation
  - Smart Medical Systems
  - Integrated Human Function

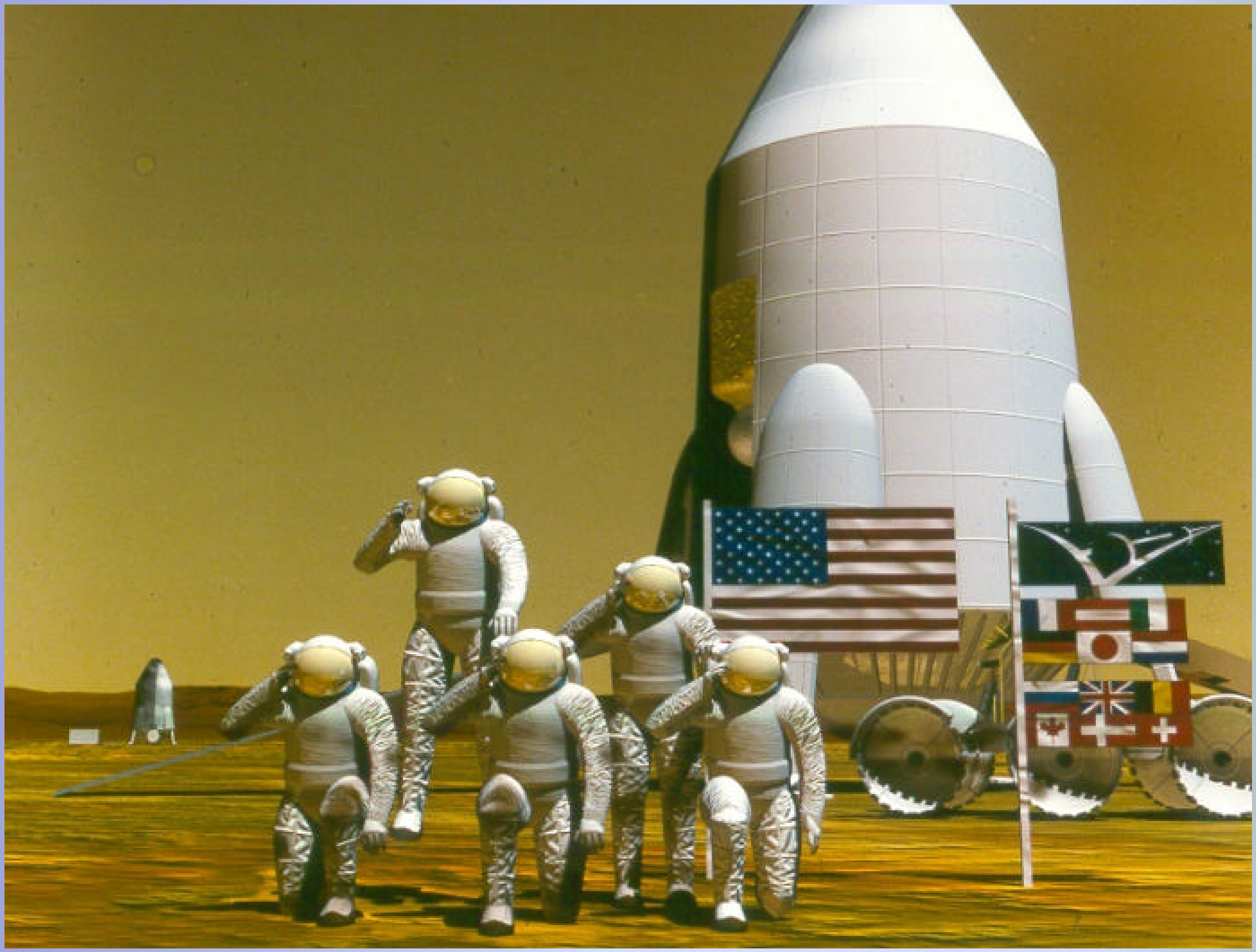
Future Directions with NSBRI

- A single NASA/NSBRI team
  - NSBRI to provide intellectual leadership, coordination and management of selected functions
  - A range of options is being discussed with NSBRI
- This team will use the Critical Path Roadmap to provide a common framework addressing human adaptation/countermeasures in structured manner
- A detailed tactical planning model is being developed to determine how much of current base program can/should be re-focused to be more complementary to Bioastronautics effort

Summary

Building on the history of human space flight, NASA and the International Partners are using all available knowledge to ensure the health, safety and optimum performance of human spaceflight for the betterment of all mankind.

Space Exploration



Bioastronautics Institute
An Expanded NSBRI

The National Space Biomedical Research Institute (NSBRI) will expand its arena of investigation while delving more deeply into existing areas of research

- Competitively add major consortium members
- Add NSBRI discipline teams
  - Integrated human function
  - Neurobehavioral & psychosocial health
  - Exercise & nutrition
  - Smart medical systems
- Expand core teams tasks
- Develop additional national, international, & private sector partnerships

Bioastronautics Institute (cont'd)

- Initiate tactical planning utilization effort
  - In-flight biomedical research
  - Coordination/Management
  - Implementation support
- Integrate biologically-inspired technologies into project paths
- Collaborate directly with space medicine activities

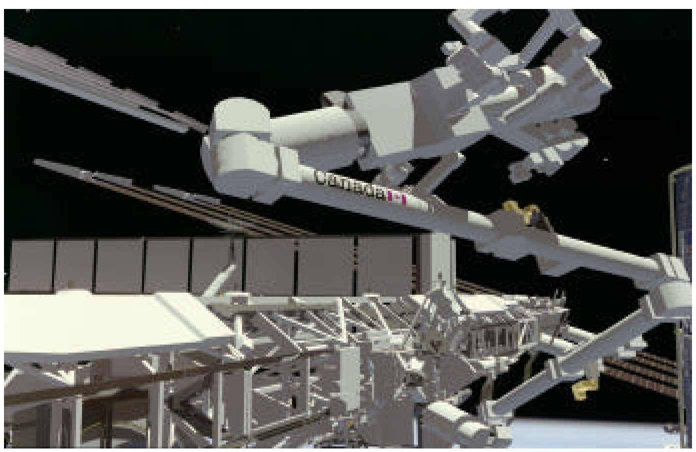
Technology Research Directions

- Habitation Systems
  - Closed-loop life support
  - Advanced EVA systems
  - Radiation protection
  - Autonomous environmental control technologies
- Human Adaptation/Countermeasures
- Health Care
  - Advanced medical systems
  - Immersive virtual environments

- Breakthrough Technologies
  - Biologically-inspired technologies
  - Digital Human
  - Common sense logic
  - Autonomous, individualized health care systems
  - Human-machine interfaces

Missions

- International Space Station*
  - Utilize in-flight resource availability
  - Research platform for human space flight qualification
  - Long-duration testbed for integrated advanced systems
- Shuttle & short-duration flight as required by critical path
- Robotic exploration
  - Mars human robotic program
    - Traditional
    - Micro-missions
  - Other solar system missions



* Increased budget resources for ISS not part of this augmentation

Laboratories

Integrate Center Strengths

JSC

- Crew re-habilitation and training
- Baseline data collection
- Biomedical & clinical research
- Advanced systems in medicine, life support, & safety
- Biotechnology & bioengineering

JPL

- Nano-technology
- Human-machine interfaces

MSFC/GRC

- Materials
- Combustion
- Fluids
- Commercial

ARC

- Cyber-medicine
- Medical informatics
- Human-machine interfaces

Education & Outreach

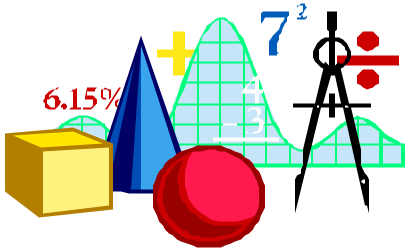
The augmentation includes a directed education and outreach component

Station era represents a new paradigm for outreach opportunities

- Curricula for elementary & secondary students
- Web resources & interactive learning systems
- Involvement of secondary, undergraduate, graduate, & postdoctoral students in the research process
- Interactive telescience interation with flight research

Information technologies present new, cost-effective solutions to involve a broad segment of the public

Human space flight continues to inspire the public to pursue interests in science & technology



Future Research Opportunities

- telemedicine and remote medical monitoring
    - remote medical therapeutics
    - non-invasive diagnostic and monitoring techniques
    - blood and fluid replacement systems
    - wound healing in microgravity
    - surgical techniques in microgravity
    - fracture healing in microgravity
    - stabilization and transportation criteria

Transitioning to an NSBRI-Focused Program

- Removed senior level scientists from JSC biomedical support contractor
  - Utilized NSBRI to transition them into academic or other career paths
- Increasing collaborations between intramural and NSBRI research teams
  - Two major meetings to date for information transfer
  - NSBRI involved in creating "Critical Path Roadmap Plan"
  - Intramural support to current 12 workshops being conducted to formulate next NSBRI solicitation
- Integrating NSBRI and intramural research
  - NSBRI research treated at total biomedical research symposium
  - Multiple collaborators, 11 funded Co-Investigators
  - Exploring feasibility of NSBRI IPA or direct involvement in several major positions
    - Lead of exercise team/effort
    - Radiation biologist
    - Food technology lead

We now have a common understanding of problem scope and means to address it; the augmentation provides the required resources.

Planning Assumptions

- Concrete management expectations
  - Annual expenditures for NSBRI ~ $50 Million per year
  - Increased NSBRI involvement in JSC "operational" activities
    - HRF development and utilization
    - Health care/research issues such as acoustics and gender specific considerations
  - Adherence by NASA/NSBRI team to the jointly developed Critical Path Roadmap
- Probable management expectation
  - Greater NSBRI role in the overall "coordination" of the Biomedical Research and Countermeasures program
- Possible approaches
  - NSBRI as an NGO (non-government organization) for the overall implementation of the biomedical research program on Shuttle/ISS
  - NSBRI as a focal point for NASA interaction with the National Cancer Institute
  - NSBRI as the integrating agent for NASA/NSBRI advanced technology activities (e.g., smart suits, Biologically Inspired Technologies)
- Additional option
  - Collaborative involvement of NSBRI with Space Medicine Program
    - Participation on flight teams to understand medical care/countermeasure issues more directly
    - Support for clinical research activities

Bioastronautics Research Program Strategy